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HIGH ENERGY ASTRONOMY OBSERVATORY MISSION C PHASE A FINAL REPORT

CASE FILE COPY

Volume I — Executive Summary

By Program Development

January 1972

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

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16. ABSTRACT

In response to a request from the Office of Space Science, a Phase A study of the High Energy Astronomy Observatory Mission-C (HEAO-C) was undertaken by the George C. Marshall Space Flight Center. Results of this study are reported in three volumes, Volume I containing an executive summary, Volume II containing the preliminary analyses and conceptual design of a baseline mission and spacecraft, and Volume III containing supporting technical data and experiment and spacecraft alternatives.

The HEAO-C is the third of four planned missions in the High Energy Astronomy Program. The primary objective of the first two missions, HEAO-A and -B, is a scanning survey of the celestial sphere to study X rays, gamma rays, and cosmic rays, and to map locations of high energy sources; the primary objective of HEAO-C is a detailed study of the more interesting high energy sources, using grazing-incidence X-ray telescopes and a spacecraft pointing accuracy of ±1 arc minute.

A principal design goal for the HEAO-C spacecraft was to maximize commonality with the spacecraft designed for Missions A and B; technical transfusion between the designs required the Phase A study to be accomplished in parallel with the Phase B definition of the precursor spacecraft. Plans call for a HEAO-C launch between 1 and 1½ years after the launch of HEAO-B.

The HEAO-C will be launched from ETR on the Titan IIID and placed into a 270 nautical mile circular orbit with a 28.5 degree inclination; the Phase A baseline concept weighs under 16 000 pounds, provides the required ±1 arc minute pointing accuracy, carries three grazing-incidence X-ray telescopes with multiple focal plane experiments plus several supporting experiments, and is designed for a two year operational life. The HEAO-C is a candidate for early satellite retrieval with the Space Shuttle.

17. KEY WORDS High Energy Astronomy Observatory Scientific Satellite High Energy Space Physics Conceptual Satellite Design Unmanned Spacecraft	18. DISTRIBUTION STATEMENT STAR Announcement Erich E. Goerner Director, Preliminary Design Office

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Phase A program management was assigned to the Space Physics Group in the Mission and Payload Planning Office of Marshall Space Flight Center's Program Development Organization. Program Development's Preliminary Design Office was assigned responsibility for the Phase A technical analyses and engineering design; the Program Planning Office assisted with cost analyses and trades; and Program Development's HEAO Task Team (now Program Management's HEAO Office) provided the required liaison with the Phase B contractors for HEAO missions A and B.

Science and Engineering's Laboratories gave valued consultation and support in many technical areas; of special note was the assistance of the Space Sciences Laboratory in the area of experiment requirements and the Astronautics Laboratory and Product Engineering and Process Technology Laboratory in the area of materials selection.

Grateful acknowledgment is made of the excellent efforts of MSFC's support contractor team. Teledyne Brown Engineering, under Contract NAS8-20073, made substantial contributions throughout the study and much of their design and analysis effort is incorporated in this final report.

The Physics and Astronomy Division of OSS worked closely with MSFC in establishing appropriate mission objectives and requirements and assigned the experiment complements to be investigated — both for the baseline concept and the candidate alternatives.

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LIST OF ACRONYMS

ACN	Ascension Island
AD	aspect detector
AS&E	American Science and Engineering
ASCS	attitude sensing and control system
BOL	beginning of life
C&DH	communication and data handling (system)
CCS	curved crystal spectrometer
CFD	coarse flare detector
CIU	cable integration unit
CMD	command
CMG	control moment gyro
COMM	communication (system)
CRO	Carnarvon
CYI	Canary Islands
DHS	data handling system
DOD	depth of discharge
DSS	digital sun sensor
EIA	electrical integration assembly
EOM	end of mission
EPS	electrical power system

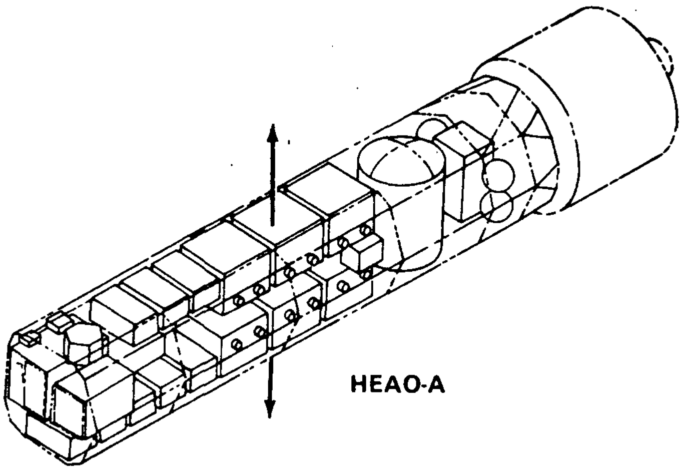
LIST OF ACRONYMS (Continued)

ERTS	Earth Resources Technology Satellite
ESE	electrical support equipment
FCS	flat crystal spectrometer
FFD	fine flare detector
FHST	fixed head star tracker
FOV	field of view
FWHR	filter wheel high resolution
FWLA	filter wheel large area
FWLE	filter wheel low energy
GEP	Goddard Experiment Package
GSFC	Goddard Space Flight Center
GWM	Guam
HAW	Hawaii
HEAO	High Energy Astronomy Observatory
HR	high resolution
HRID	high resolution imaging detector
LA	large area
LAID	large area image detector
LBD	low background detector
LE	low energy

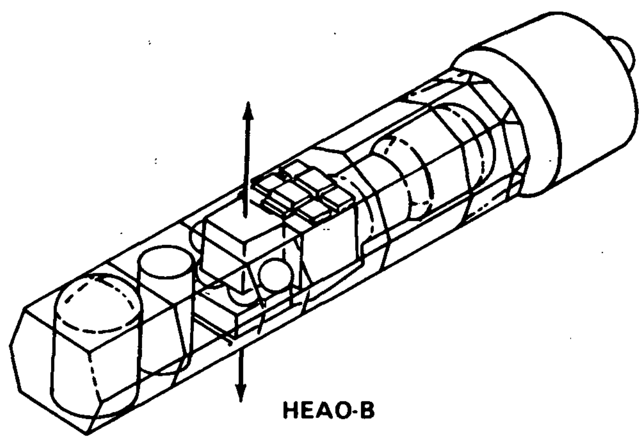
MIB	minimum impulse bit
MIT	Massachusetts Institute of Technology
MLI	multilayer insulation
MPC	monitor proportional counter
MSFC	Marshall Space Flight Center
MSFN	Manned Space Flight Network
MUX	multiplexer
OAS	Orbit Adjust Stage
OG	objective grating
PCM	pulse code modulator
PI	principal investigator
PSD	position sensitive detector
PSK	phase shift keyed
RCS	reaction control system
REA	reaction engine assembly
REM	reaction engine module
ROM	read-only memory
SAN	Santiago
SCS	satellite control section

LIST OF ACRONYMS (Concluded)

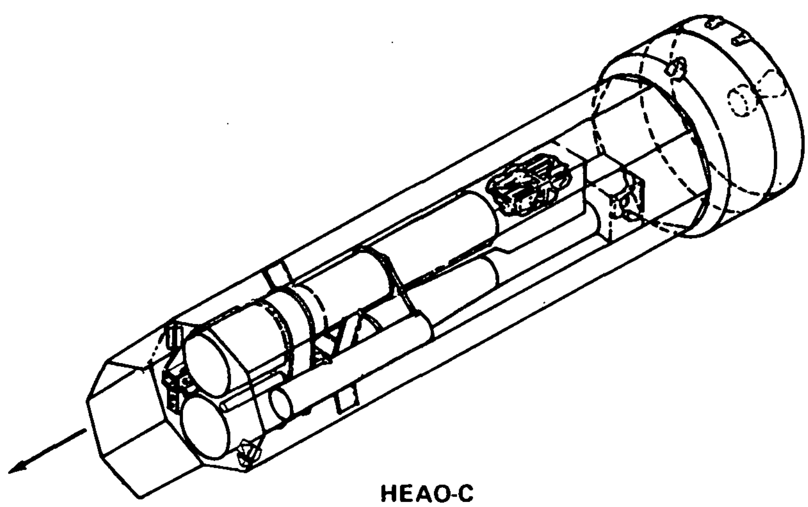
SEC	secondary electron conduction (vidicon)
SSD	solid state detector
TEX	Texas
UV	ultraviolet
WASS	wide angle sun sensor



HEAO-A



HEAO-B



HEAO-C

TYPICAL HEAO EXPERIMENT LAYOUTS
SHOWING PRINCIPAL VIEWING DIRECTIONS

CHAPTER I. INTRODUCTION

A. Mission Description

The High Energy Astronomy Observatory Mission C (HEAO-C) is the third of four planned satellite missions in the National Aeronautics and Space Administration's High Energy Astronomy Program. The overall objective of this program is to obtain high quality, high resolution data on cosmic rays, gamma rays, and X-rays throughout the celestial sphere; data will include information on the structure, spectra, polarization, and, where applicable, source location.

The primary objective of the first two missions, HEAO-A and HEAO-B, is to accomplish a scanning survey of the celestial sphere, with emphasis on identifying and mapping source locations and investigating emitted energy to the extent possible within the constraints of both time and experiment detector capability. Thus, the first two satellites will operate primarily in a scanning mode and only limited time will be available for the inertial or "pointing" mode, this percentage of time increasing for the second mission as compared to the first. Both spacecraft will be capable of a pointing accuracy of ±1 degree, or better.

The HEAO-C mission will follow the HEAO-B mission by 1 to 1 1/2 years and will be devoted entirely to the "pointing" mode, with a spacecraft pointing capability of ±1 arc minute, or better. Principal scientific instruments on board will be the grazing-incidence X-ray telescopes, with multiple experiments (detectors) positioned into and out of the focal point region. Thus, HEAO-C will operate in a manner similar to a ground-based observatory in that various experiments will time-share the telescopes. In addition, several stationary experiments will be rigidly mounted to the optical bench alongside the telescopes to fill out the experiment complement and to provide background measurements.

B. Study Objective and Approach

The objectives of the Phase A study were to determine mission feasibility, to study several alternative experiment complements, to investigate promising spacecraft alternative concepts, and to study a baseline experiment and spacecraft concept to sufficient depth to establish hardware feasibility.

The principal design goal for the HEAO-C spacecraft was to maximize commonality with the HEAO-A/B spacecraft in order to maintain cost effectiveness throughout the HEAO program.

The Phase A study of HEAO-C was initiated soon after the start of the Phase B definition contracts for the HEAO-A/B missions and spacecraft and progressed concurrently with them. Technical transfusion between the in-house Phase A study and the Phase B definition contracts influenced both design approaches and achieved the desired cost-effective commonality. This was reflected in design decisions incorporated in the Request for Proposal issued by Marshall Space Flight Center for the HEAO Phase C/D for Missions A and B.

Technical effort on the Phase A study was concluded prior to receipt of the Phase C/D proposals and, consequently, does not reflect the exact manner in which the most recent version of the HEAO-A/B spacecraft will evolve through modification to accomplish the HEAO-C mission. Continuing study and design iteration will be required by the Phase C/D contractor, with special emphasis given to the experiments in order to incorporate improved definition of both requirements and hardware.

C. Conclusions

Results of the Phase A study indicate that modifications to the HEAO-A/B spacecraft to accomplish the HEAO-C mission are entirely feasible; in general, spacecraft components which must be different result from the more stringent requirements for pointing accuracy, higher reliability, and longer operational life, and the different experiment mounting and accommodation requirements.

Study results are reported in three volumes, Volume I containing an executive summary, Volume II containing the preliminary analyses and conceptual design of the HEAO-C baseline mission and spacecraft, and Volume III containing supporting technical data and experiment and spacecraft alternatives.

CHAPTER II. HEAO-C EXPERIMENTS

In contrast to the experiments on the HEAO-A and HEAO-B satellites which study both cosmic radiation and hard and soft X rays and gamma rays, the baseline experiments proposed for HEAO-C concentrate on the soft to medium-hard X-ray wavelength range, 1 to 100 Å or, approximately, 0.10 to 10 keV. Other comparative features among the three payloads are shown in Table II-1.

The goal of X-ray astronomy, like that of optical astronomy, is the determination of the physical properties of the sources (e.g., size, mass, and temperature) and the mechanisms by which their radiation is produced and emitted to space. These properties and mechanisms must be determined from a few observable quantities: spectra, luminosities, and positions. The various spectrometers, filters, and gratings on the HEAO-C X-ray experiments permit measurement of the intensity of emitted radiation at different spectral wavelengths with different resolutions and dispersions. Provision is also made for determining the integrated intensity over a wide wavelength range — the apparent luminosity.

TABLE II-1. COMPARISON OF HEAO-A AND -B TO HEAO-C

	A and B	C
Experiment Weight	12 500 lb	7600 lb
Pointing Required	±1 deg	±1 arc min
Smallest Field of View	1 deg x 1 deg	2.1 x 2.1 arc min
Objectives	Locating Sources	Studying Sources
Mode	Scanning	Pointing
Sources Known at Launch	100	3000 to 4000

The aspect determination system can be used to determine the celestial coordinates of the sources to within one second of arc, which in most cases is sufficiently precise for identification of their optical counterparts. Once these identifications have been made, the distances of the sources can be estimated if the sources can be correlated with optical objects whose distances are known, and the absolute X-ray luminosities can then be found. From the distance and the measured source size, the physical scale of an X-ray source can be determined. The luminosity and spectral data provide information on the temperature and energy generation processes.

Several X-ray sources have suddenly become visible where nothing had been detected previously and have, then, gradually faded again into

obscurity. These "flares" are particularly interesting, and a complete record of the progress of a flare over the two months or so of its life would be of great value. The flare detectors on HEAO-C are intended to detect the onsets of such outbursts anywhere in the sky so that they can be studied with the higher resolution instruments.

A. Baseline Experiments

The baseline experiments for the HEAO-C Phase A study are listed in Table II-2 and their responsive energy ranges in Table II-3.

The experimental packages are shown in Figure II-1 in block diagram form and depict the interrelation of the various experiment components. In Figure II-2 the locations of the experiment components on the spacecraft are shown. In some cases, where the components are not well defined, only the envelope is depicted.

Three X-ray mirrors provide images in the focal regions which are analyzed by both image-sensitive and energy-sensitive detectors. A variety of experiments can be performed simultaneously on an X-ray source over a large energy range. Other experiments are used for monitoring purposes and for spectroscopy measurements at higher energies that are inaccessible to the X-ray mirrors.

The numbers down the right side of Figure II-1 point up the possible variations and combinations of experiments and experiment equipment that are available. Not all of the combinations numbered will necessarily be used, especially under normal conditions with no failures. However, the combinations are available and some degree of redundancy is provided. The sum of variations is shown at the bottom of the column.

The number of possibilities made available by any piece of equipment is depicted by the number that appears at the upper left of the box representing that component. For example, the secondary electron conduction (SEC) vidicon has three scan modes, or fields of view, available; therefore, the number three appears at the upper left side of that box. Each filter wheel is represented as having four sections (one an open window, the other three occupied by filters); therefore, the number four appears beside that box. The objective grating and the aperture control are considered to be either in or out; therefore, there are two possibilities for each.

TABLE II-2. BASELINE EXPERIMENTS AND ABBREVIATIONS

Experiment Hardware	Hardware Abbreviation	Type of Measurement
High Resolution Telescope	HR	X-ray
Curved Crystal Spectrometer	CCS	Crystal spectrometry
HR Imaging Detector	HRID	Imaging, high resolution position determination
Objective (Transmission) Grating	OG	Objective grating spectrometry (OG and HRID used)
Filter Wheel	FWHR	Broadband filter spectrometry (FWHR and HRID)
Large Area Telescope	LA	X-ray
Solid State Detector	SSD	Nondispersive spectrometry
LA Image Detector	LAID	Imaging, faint source position determination
Filter Wheel	FWLA	Nondispersive spectrometry (FWLA and LAID)
Low Energy Telescope	LE	X-ray
Position Sensitive Detector	PSD	Imaging, position determination
Low Background Detector	LBD	Imaging, position determination
Filter Wheel	FWLE	Nondispersive spectrometry (FWLE and LBD)
Miscellaneous Experiments		
Monitor Proportional Counter	MPC	Background counter
Flat Crystal Spectrometer (Iron Line)	FCS	Crystal spectrometry
Coarse Flare Detector	CFD	Flare detection, coarse resolution (4 deg)
Fine Flare Detector	FFD	Flare detection, fine resolution (30 min)
Aspect Detector	AD	Aspect determination

TABLE II-3. EXPERIMENT ENERGY RANGES

Instrument	Energy Range (keV)	Minimum[a] Detectable Flux in 10^3 sec (erg/cm^2-sec)	Minimum Detectable Surface Brightness in 10^3 sec	Angular Resolution	Energy Resolution ($\lambda/\Delta\lambda$)	Time[b] Resolution (msec)
CCS	0.2 - 3	10^{-12}			50 - 6000	
HR Image Intensifier	0.2 - 4	$\approx 4 \times 10^{-13}$	$\approx 10^{-14}$ erg/ cm^2-sec $(arc\text{-}sec)^2$	<5 min		1
OG Spectrometer	0.2 - 2	3×10^{-12}			200	
Broadband Filter Spectroscope	0.2 - 4					
Solid-State Spectrometer	0.5 - 4	4×10^{-14}			10	0.5
Position Sensitive Proportional Counter	0.2 - 4	2×10^{-14}	10^{-14} erg/cm^2-sec $(arc\text{-}min)^2$	30 min	2 - 4	0.1
LE Telescope	0.124 - 0.62			few arc sec max		
FCS (Iron Line)	6.4 - 7.2	10^{-11}			10^3, 10^4	
Flare Alarm	1 - 10	$\approx 10^{-9}$		0.5 deg		

a. Indicates detector sensitivity for a 1000 second observation.
b. Minimum time in which an experiment can detect a change in the received flux.

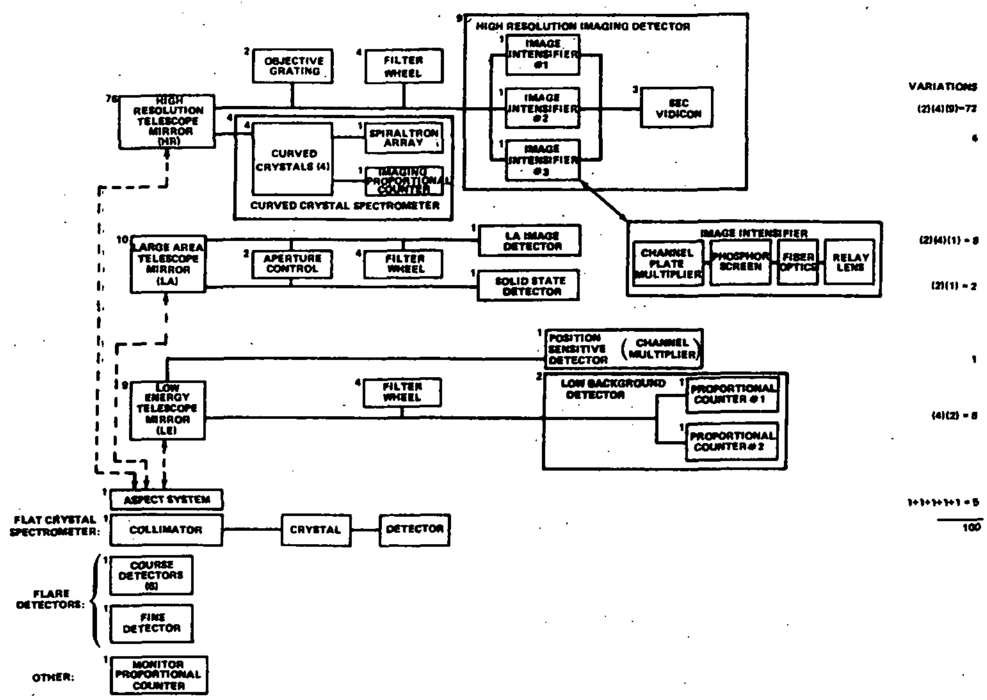


Figure II-1. Interrelations of experiment components for HEAO-C.

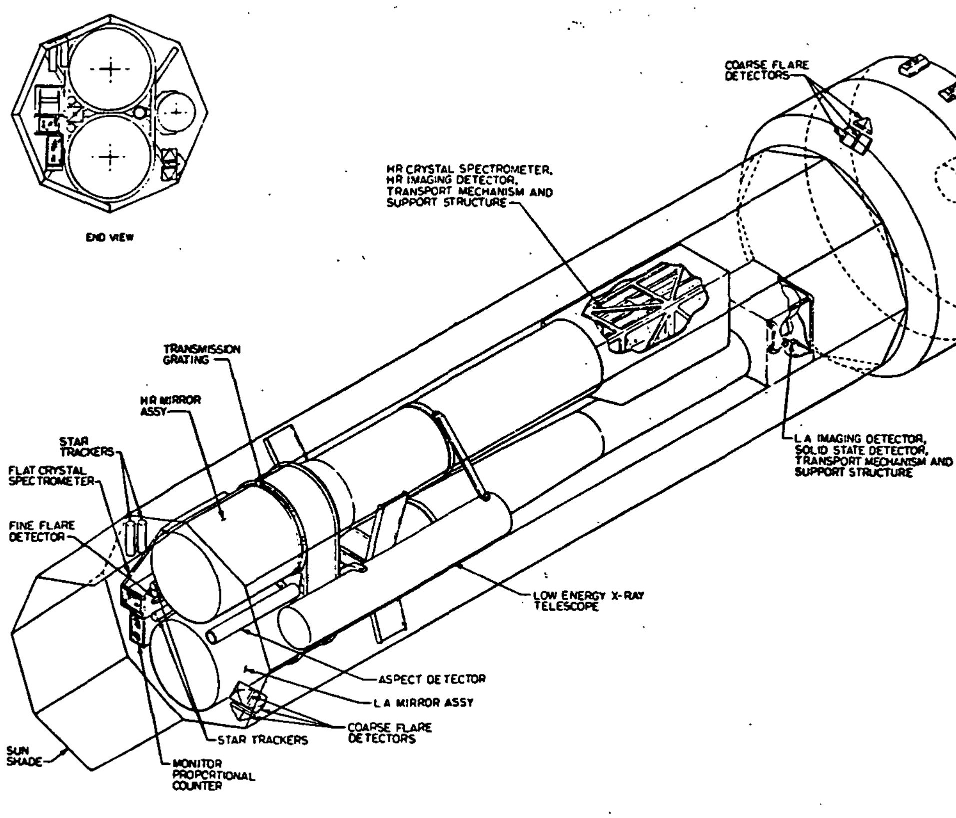


Figure II-2. HEAO-C baseline experiment layout.

Table II-4 is a listing of the power, weight, size, and field of view (FOV) of the various baseline experiments. Requirements which the telescope packages place on the spacecraft are listed in Table II-5.

The HR telescope includes a set of five confocal, parabolic-hyperbolic, grazing-incidence mirrors (Fig. II-3). Each mirror has a physical length of 44 inches and a focal length of 240 inches. The outermost mirror diameter is 36 inches. The mirrors will probably be fabricated of a low expansion glass such as Cer-Vit with a thickness of 0.5 inch. The resolution of the HR mirror will be in the arc second range, the exact value depending on the wavelength under observation and the off-axis distance of the sources.

The need for a telescope with a large collecting area at the sacrifice of high image resolution has resulted in the design of a large area (LA) mirror, shown in Figure II-3. The focusing scheme is of the Baez type; X rays are reflected at small angles off two nearly flat, paraboloidal mirror segments which are nearly perpendicular, one to the other. The entire mirror system consists of 16 sets of identical Baez modules with a front and rear section. Each section is composed of a set of 25 nearly-parallel plates. The individual plates are deformed to the proper parabolic figure by placing optical flats in a rigid holding fixture. The LA mirror assembly has a length of 49.5 inches, a diameter of 36 inches, and a focal length of 312 inches.

Both the HR and LA telescopes are designed to operate in the energy region of 0.2 to 4 keV, requiring long focal lengths compatible with small grazing angles. To observe longer wavelength X rays (lower energies), a low energy (LE), Wolter-type telescope is proposed for the HEAO-C mission. The mirror consists of a single parabolic-hyperbolic surface of Kanigen-coated beryllium. The maximum grazing angle of the first element is 2 degrees and the focal length is 72 inches. The diameter of the telescope is 20 inches.

The various detectors used in the focal region of the three telescopes and the independent ancillary experiments are described in detail in Volume II of this report.

B. Operational Considerations

Natural sources of radiation including trapped particulate radiation, cosmic rays, and earth albedo secondary cosmic radiation will produce background counting rates in the various detectors, which will ultimately determine their sensitivity. Because of the nature of the background radiation and the

TABLE II-4. EXPERIMENT POWER, WEIGHT, SIZE, AND FIELD OF VIEW

Experiment Components	Field of View (Total Angle) (min)	Size H × W × L (in.)	Total Weight (lb)	Average Power (W) Inside Tube	Outside Tube
High Resolution Telescope					
HR Mirror Assembly	60	40.5 dia × 48 long	2025		
HR Image Intensifier		10 dia × 10 long	20	13.5	
Mode 1	17 × 17				
Mode 2	2.1 × 2.1				
Mode 3	17 × 4.2				
Electronics Module		5 × 5 × 10	24		19.0
HR Crystal Spectrometer	60	In transport mechanism	397	21.0[b]	
HR Experiment Transport Mechanism		38 × 33 × 83	70	(c)	
Objective Grating	(a)	40 dia × 12 long	60	(c)	
Filter Wheel	(a)	10 dia × 6 long	40	(c)	
Structure			Excluded		
Large Area Telescope					
LA Mirror Assembly	60	40 dia × 49.5 long	2400		
LA Position Sensitive Detector	26	5 × 5 × 5	100	1.0	
Electronics Module		5 × 5 × 10	50	13.5	
Solid State Detector	7	10 dia × 18 long plus 18 in. dia sphere	90	2.0	
Electronics Module		7 × 7 × 7	25		6.2[b]
LA Experiment Transport Mechanism		38.5 × 40 × 21	115	(c)	
Filter Wheel	(a)	10 dia × 6 long	40	(c)	
Structure			Excluded		
Flare Detectors					
Coarse Detector (6)	90 × 90 (ea.)	5.5 × 8 × 3 (ea.)	120		12
Fine Detector (1)	8	10 × 10 × 48	27		(d)
Electronics Module (3)		5 × 5 × 5 (ea.)	150		28 (2 only)
Monitor Proportional Counter	1 FW[e] ½ FWHM[f]	10 × 16 × 23	98		1.0
Electronics Module		Included above	44		8.0
Flat Crystal Spectrometer (1)	1 FW ½ FWHM	25 × 19 × 63	162		17.0
Aspect Detector	7.5	10 dia × 18 long	100		8.0
Electronics Modules		5 × 5 × 10	21		6.0
Cabling			157		
On Tubes			27		
On Spacecraft			130		
Low Energy Telescope				24	
Mirror Assembly	1.5	20 dia × 26 long	400		
Position Sensitive Detector	1.5	5 × 5 × 5	30		
Low Background Detector	1.5	5 × 5 × 6	30		
Filter Wheel		10 dia × 6 long	30		
Transport Mechanism		Included above	50		(g)
Structure			300		

a. Depends on detector.
b. Not to be included in maximum power configuration.
c. Uses 6 W during operation; duty cycle is negligible.
d. Fine detector and its electronics use 2 W and 8 W, respectively, during operation; used only during flare observation.
e. Full width.
f. Full width, half maximum.
g. Uses 6 W during operation; duty cycle is negligible.

TABLE II-5. REQUIREMENTS AND SPECIFICATIONS OF THE BASELINE TELESCOPE PACKAGES

Principal Investigator	R. Giacconi	J. Underwood
Principal Institution	AS&E[a]	GSFC[b]
Other Institutions	Columbia University GSFC MIT[d]	MSFC[c] University College, London Cambridge University
Experiment	X-ray Telescopes: High Resolution Telescope (HR) Large Area Telescope (LA)	X-Ray Telescope: Low Energy Telescope (LE)
Wavelength Range (Å)	3.1 to 62 (Focal Plane Exps)	20 to 400
Energy Range (keV)	4.0 to 0.2	0.62 to 0.124
Resolution	≈1 arc sec max	Variable, a few arc sec to 1 deg
Typical Observing Program	≈1 source/orbit	1 source/orbit (nighttime hemisphere preferred)
Expected Maximum Duration of Pointing per Target	≈ ½ orbit continuous typical; 1 week maximum integral viewing time[e]	≈½ orbit continuous (nighttime pointing only, preferred)
Alignment	(f)	(f)
2 Axis Pointing Accuracy	(f)	(f)
Pointing Accuracy About Optical Axis	No spec.[g]	No spec.[g]
2 Axis Pointing Stability	No spec.	(h)
Pointing Stability About Optical Axis	No spec.[i]	(h)
Maximum Allowable 2 Axis Pointing Jitter Rate	1 arc sec/sec	No spec.
Maximum Allowable Rotation Rate About Optical Axis While Pointing	1.5 arc min/sec[i]	No spec.
3 Axis Pointing Aspect Accuracy (For ground use) Note: Giacconi provides ±1 arc sec	Commensurate with pointing accuracy	Commensurate with pointing accuracy
Precision Slow or Scan Maneuvers	Not required	Not required
Clock Resolution	1 msec	0.1 msec
Clock Accuracy	0.1 msec	0.1 msec
Clock Stability Long-Term Drift Rate	$\pm 5 \times 10^{-9}$/day (-40° C to +70° C)	1 msec per orbit
Short-Term Drift Rate	$\pm 2 \times 10^{-10}$/sec (at constant ambient)	No spec.
Temperature Limits	Bench temperature limits to be determined during study by deflection limits; lens transverse limits ±5° F; lens axial limits ±2.5° F	15° C ±5° C external
Deflection Limits[j] Lateral	±0.04 in. across each tube (allow only 0.005 of this for thermal.)	≈1 to 5 arc min
Longitudinal	±0.004 in. along HR tube ±0.04 in. along LA tube	Unknown

TABLE II-5. (Concluded)

Principal Investigator	R. Giacconi	J. Underwood
Principal Institution	AS&E[a]	GSFC[b]
Other Institutions	Columbia University GSFC MIT[d]	MSFC[c] University College London Cambridge University
Experiment	X-Ray Telescopes: High Resolution Telescope (HR) Large Area Telescope (LA)	X-Ray Telescope: Low Energy Telescope (LE)
Radiation Limits	No spec.	No spec.
Launch Environments	Titan OK (Shock mounts may be required)	Titan OK
Command Requirements	300	64
Command Execution Time Resolution	1 sec in 24 hr	Unknown
Command Format	24 test bits, 6 access code bits	24 test bits, 6 access code bits
Radio Frequency Interference Requirements	No spec.	Assumes ATM[k] specs.
Meteroid Protection Required	No spec.	No additional required
Magnetic Fields Limits[l]	No spec.	1 oersted
Size (in.)	HR 315 long × 45 dia (+exp. box corners) LA 343 long × 45 dia (+exp. box corners)	120 long × 24 dia
Weight (lb)	5456 (excludes structure)	840 (includes structure)
Focal Length (in.)	240 (HR) 312 (LA)	70
Power Required (watts)		
Standby	130 (including 81 W computer)	None, scientifically; possibly needed thermally
Average	130 (including 81 W computer)	24
Peak	142 (including 81 W computer)	50
Data Rate Required (kbs)	20	<1
Voltage (Vdc)	28 ±2	28 ±2
Field of View (deg)	≈1 (lens)[m]	1.5 (lens)[m]

a. American Science and Engineering
b. Goddard Space Flight Center
c. Marshall Space Flight Center
d. Massachusetts Institute of Technology
e. Interruptions of up to 2 min per orbit are permissible.
f. Maintain alignment of telescopes and miscellaneous experiments within ±1 arc min of each other; point spacecraft reference axis with 2 axis pointing accuracy of ±1 arc min.
g. Present attitude sensing and control system pointing accuracy about spacecraft reference axis is ±5 arc min.
h. Use Giacconi requirements for purposes of this study (1 to 5 arc sec per 1/2 orbit is Underwood original requirement).
i. Present attitude sensing and control system constraints are ±5 arc min pointing stability about optical axis and ±5 arc sec per sec rotation rate about optical axis while pointing.
j. These represent maximum allowable relative shift between detector and focal point (absolute expansion of either is not limited); allow only one-half of this for thermal.
k. Apollo Telescope Mount
l. The telescopes and miscellaneous experiments should be compatible with typical field profiles inside the spacecraft.
m. See Table II-3 for detector fields of view.

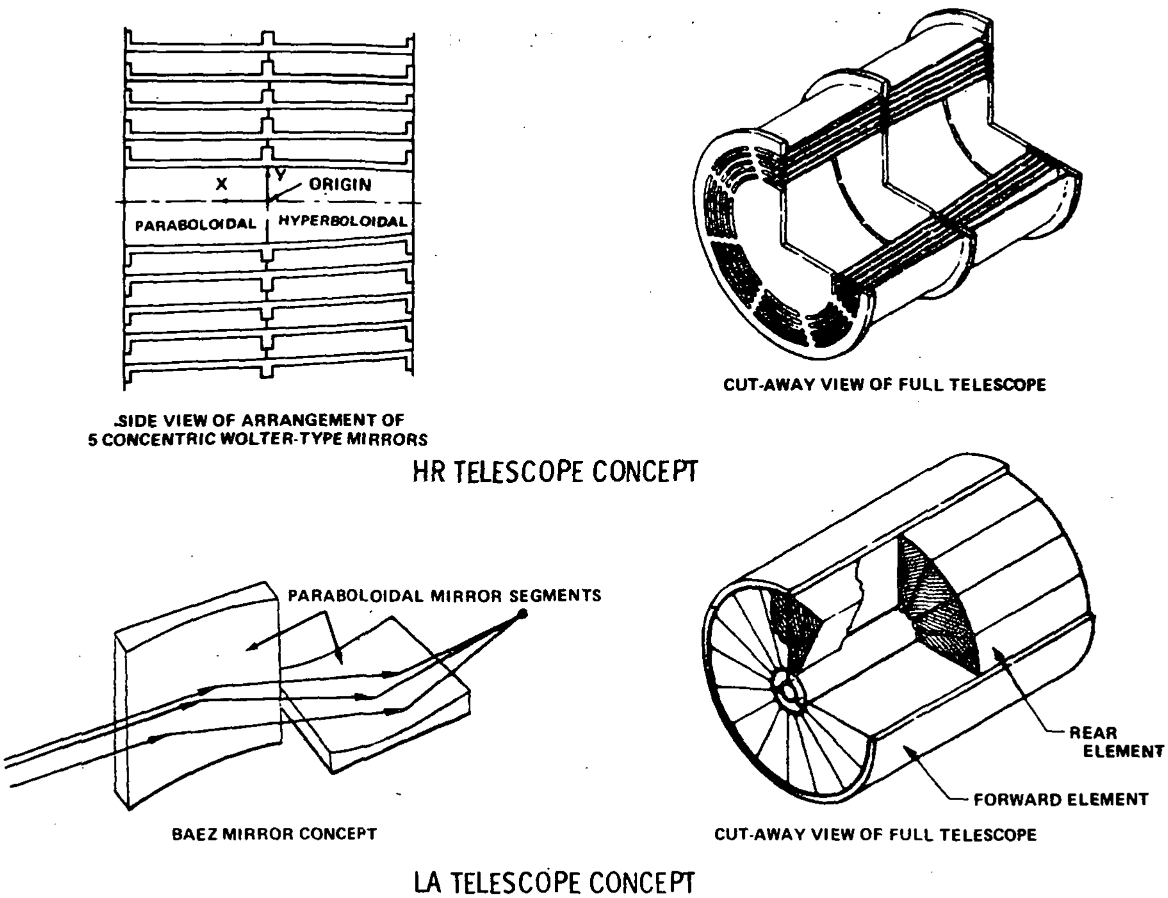


Figure II-3. High resolution and large area X-ray telescope concepts.

possibility of introducing additional secondary radiation, it is impractical and probably not advantageous to provide radiation shielding capabilities aboard the HEAO-C spacecraft beyond those internal to the detectors themselves. Trapped radiation in the region of the South Atlantic Anomaly will produce an intolerable background radiation level which will prevent useful observations during transit. To avoid damage to sensitive detectors, high voltage circuits will be shut down before saturation limits are encountered. Analysis has shown that only a few percent (less than 10 percent) of mission viewing time will be sacrificed since some transit time will correspond with target occultation and spacecraft maneuvers.

At various times during the HEAO-C mission, the proportional counters must be purged of their gases and refilled to the proper pressure. These gases include argon and xenon and small amounts of quenching gases such as carbon dioxide and methane. The frequency of these operations will be determined by

proportional counter lifetime and leakage rate information obtained from the HEAO-A experiments. The total weight of the gas resupply system is estimated to be slightly in excess of 11 pounds for the HEAO-C spacecraft and is included in the experiment weights. The gas quantities required for HEAO-C are shown in Table II-6. The gas quantities required are much less than in HEAO-A and -B because the detector faces are so much smaller and, therefore, leak less gas. Counter gases will be vented to outer space in a manner which will not introduce serious disturbance torques to the spacecraft, i.e., slowly and through a nonpropulsive vent.

TABLE II-6. PURGING AND QUENCHING GAS QUANTITIES REQUIRED

Experiment	Counter Gas	Amount Of Resupply Gas Needed
Large Area Image Detector	Propane	1 lb
Monitor Proportional Counter		
Counter A	Propane	10
Counter B	90% argon, 10% CO_2	0
Coarse Flare Detector	90% argon, 10% CO_2	0
Fine Flare Detector		0
Low Energy Telescope		1 liter

Experiments will have to be calibrated for the subsequent data to be effectively interpreted. There are two possibilities for calibration: (1) external calibration and (2) internal calibration. External calibration will consist of choosing a known stable stellar source and recording the standard observations. Since the magnitude and other parameters of the source are already known, a zero point, or baseline, is thereby established for the later observations. Internal calibration might consist of choosing a known radioactive source of a certain flux and including it in the spacecraft behind an appropriate shield. At intervals, the source would be swung into the field of view of the experiment and measurements taken to determine the efficiency of the detector, again establishing a zero point or baseline for subsequent observing. After initial spacecraft and experiment checkout, calibrations will be executed periodically. In the present timeline, simultaneous external and internal calibrations have been scheduled on a monthly basis, although more frequent calibrations are possible, especially for the internal calibration scheme.

Definition of the experiments baselined for the study had not matured sufficiently to establish realistic launch environment specifications. To ensure adequate protection, shock-mounting of the optical bench was incorporated into the Phase A design concept. Ultimately, detailed dynamic analysis of the total flight vehicle must be performed to determine the acceptability of the loads on the experiments.

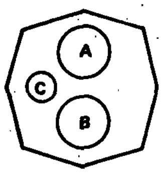
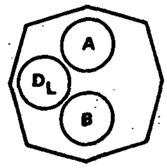
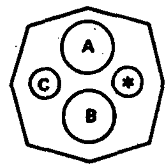
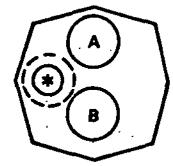
C. Alternate HEAO-C Experiments

During the course of the Phase A study, three alternative experiment packages were assigned for review (Table II-7). Each of the options included a UV telescope in addition to a high energy experiment complement.

Unlike the HEAO-A/B spacecraft, all primary experiments on HEAO-C view along the longitudinal or long axis of the spacecraft. Thus, frontal viewing area is in great demand and spacecraft cross-sectional area becomes a principal constraint in experiment packaging. Although the HEAO-C subsystems could be designed to accommodate any of the three options, each option violated the structural envelope and would require reduction of some experiment diameters and/or elimination of one of the proposed experiments to be acceptable. In addition, option 4 had to be discarded once the decision had been made to retain the OAS as an integral part of the Observatory since telescopes are viewing in both longitudinal directions.

Although not investigated in detail, it appeared likely that the alternative experiment packages would add to mission complexity when compared to the baseline package. Some compromise would seem necessary between the diverging scientific objectives of high energy and ultraviolet astronomy and an additional time-sharing of targets-of-interest would probably be required.

TABLE II-7. HEAO-C ALTERNATE EXPERIMENT PACKAGES

OPTION 1 BASELINE	OPTION 2	OPTION 3	OPTION 4
		 *D_S	 *C POINTS WITH A & B D_L POINTS OPPOSITE C
A. HR Telescope Image Intensifier, Objective Grating, Filter Spectrometer, Curved Crystal Spectrometer	A. Same as 1	A. Same as 1	A. Same as 1
B. LA Telescope Solid State Detector, Filter Spectrometer, Position Sensitive Detector	B. Same as 1 except for C. below	B. Same as 1	B. Same as 1
C. LE Telescope Filter Spectrometer, Position Sensitive Detector	C. None (moved to LA telescope)	C. Same as 1	C. Same as 1
D. UV Telescope (none)	D. Large UV Telescope (GEP)[a] 10 ft long 40 in. dia 982.2 lb	D. Small UV Telescope (smaller and lighter than large UV)	D. Same as 2
E. Miscellaneous (not shown) 1. All-Sky Flare Detector 2. Fine Flare Detector 3. Monitor Proportional Counter 4. Flat Crystal Spectrometer	E. Same as 1	E. Same as 1	E. Same as 1

a. Goddard Experiment Package

CHAPTER III. MISSION ANALYSIS

The HEAO-C mission requirements and guidelines are summarized in Tables III-1 and III-2. Principal mission considerations investigated during the Phase A effort are discussed in the following paragraphs.

TABLE III-1. HEAO-C MISSION REQUIREMENTS

• 2 Year Operational Lifetime
• Inertial "Pointing" Mode Throughout Mission
• ±1 arc min Pointing Accuracy, 1 arc sec/sec Jitter Rate
• Continuous Viewing with Normal to Solar Array as Much as 15 degree Half-Cone Angle from Earth-Sun Line
• Limited Viewing (one orbit/day) with Normal to Solar Array as much as ±30 degrees from Earth-Sun Line (maximum roll = 15 degrees)
• All-Sky Viewing on Dark Side of Orbit
• All-Sky Flare Detection Capability
• Capability for Scan of Large Source and Long Dwell Time on Single Source

TABLE III-2. HEAO-C MISSION GUIDELINES

• Launch from ETR on 3/21/77
• Titan IIID/OAS Launch Vehicle
• OAS Remains Attached to Spacecraft
• Use HEAO-A and -B Tracking Network (MSFN)
• Minimum Tracking Altitude = 140 n. mi.
• 3σ Dispersion for Titan IIID Injection Orbit
(Selected Orbit: 270 n. mi., i = 28.5 deg circular)

A. Orbit Selection

The objective of a 2 year operational lifetime coupled with the launch vehicle and launch date guidelines were the primary determinants of orbit altitude. Commonality with the earlier HEAO missions influenced orbit inclination by dictating the use of the HEAO-A/B ground tracking network. Although the latter had not been specifically identified, investigations confirmed that HEAO-C would be compatible with all of the candidate alternatives. Consideration was given to ground station contact time, interference from Van Allen radiation on the HEAO-C experiments and subsystem components, and various source viewing and occultation effects on orbit selection; however, none of the foregoing were of dominating influence.

A 270 nautical mile circular orbit with an inclination of 28.5 degrees was selected for the HEAO-C mission — 270 nautical mile altitude to assure a useful 2 year orbital lifetime (i.e., decay altitude at 2 years not less than 140 to 150 nautical miles to avoid unrealistic reduction of ground station contact time); circular for tracking convenience; 28.5 degree inclination for tracking network compatibility and to maximize payload for the ETR launch.

Figure III-1 shows the variation in orbit lifetime with the weight of the HEAO-C (spacecraft plus OAS). Since HEAO-C operates in an inertial

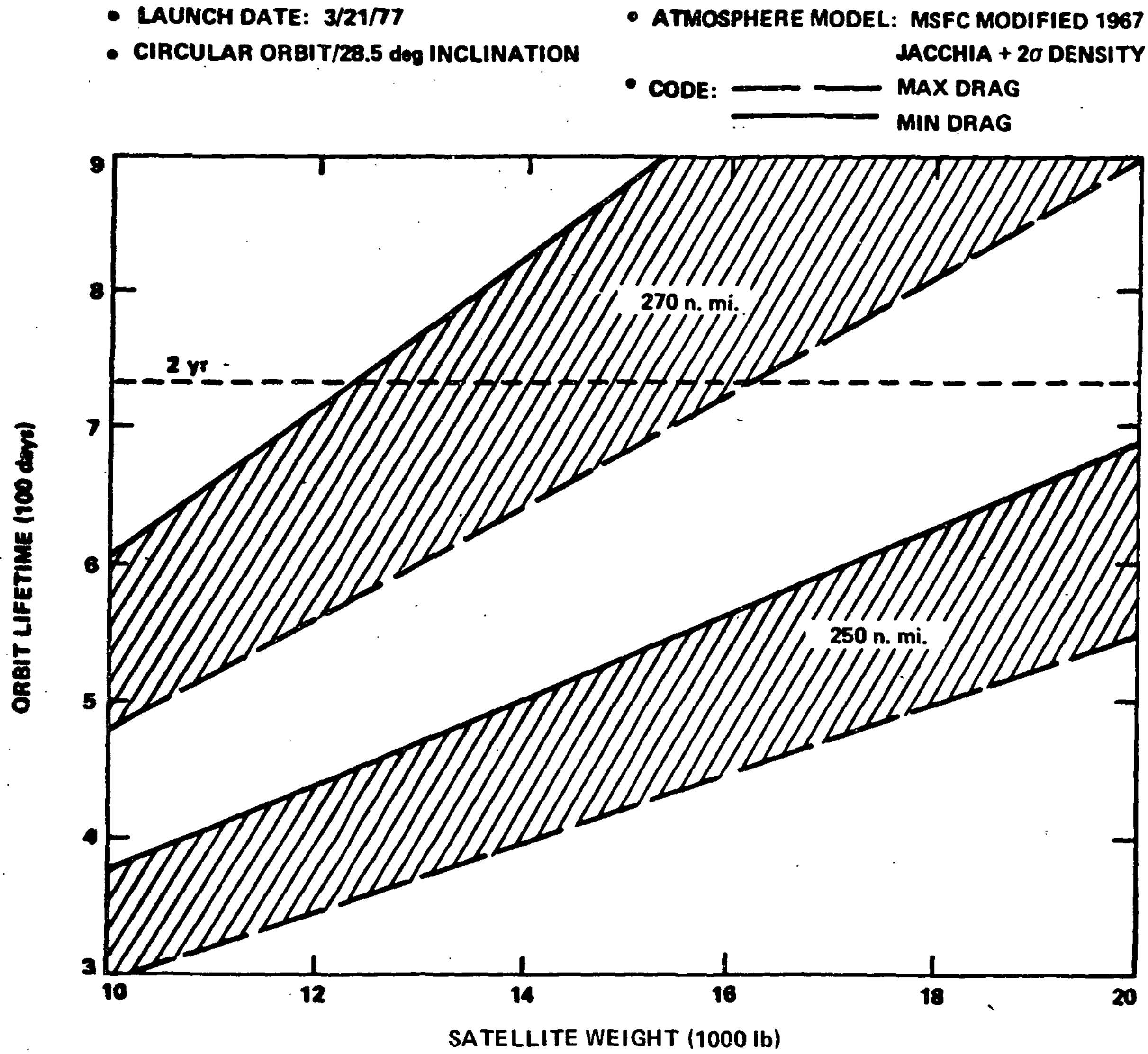


Figure III-1. Variation in orbit lifetime with weight of HEAO-C/OAS.

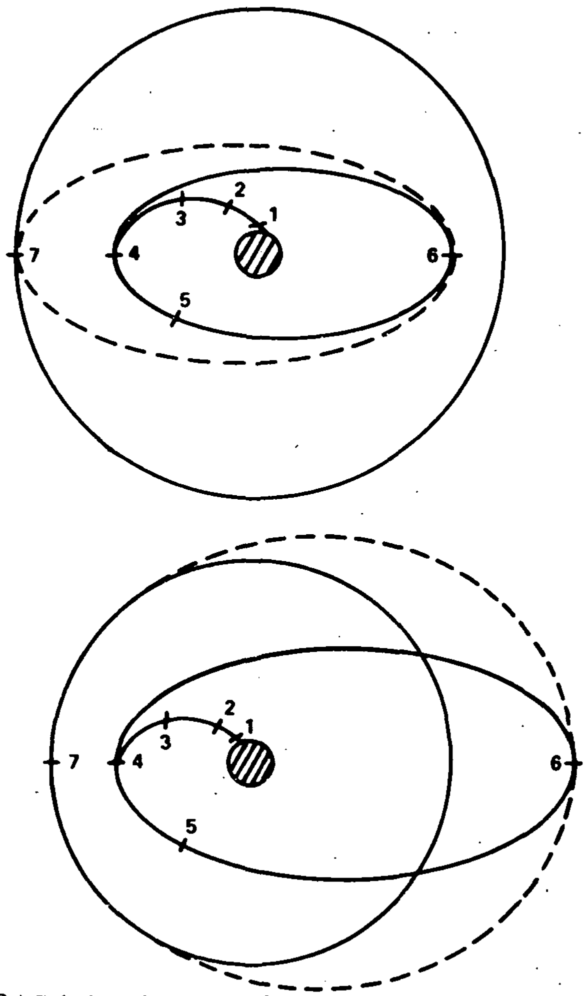
pointing mode, the lifetime prediction is bounded by maximum and minimum values which are a function of the satellite orientation to the orbital velocity vector. Orbital lifetimes are also a function of atmospheric density which fluctuates in conjunction with the 11 year cyclic solar activity; lower minimum altitudes are possible with launch dates in 1975 and 1976, than in the 1977 to 1978 time period because of the lower solar activity.

B. Launch Vehicle Performance

TABLE III-3. OAS PERFORMANCE TO 270 N. MI., 28.5 DEG, CIRCULAR ORBIT FROM 103 BY 317 N. MI. TITAN IIID INJECTION ORBIT (3 σ DISPERSION)

	(lb)
Weight at OAS Ignition	25 558
Propellant Consumed	1 240
Cutoff Weight	24 318
HEAO-C Phase A Weight	15 585
Suggested Phase B Control Weight (20% contingency)	18 702
Margin for Growth (30%)	5 616

The Titan IIID/OAS launch vehicle is similar to that used for the earlier HEAO missions. Because of the Titan IIID open-loop guidance system (1.0 percent programmer), a 3σ worst-case dispersion (off-nominal) was assumed for performance estimates. Table III-3 summarizes the performance capability and Figure III-2 illustrates both nominal and off-nominal injection profiles.



NOMINAL FLIGHT PROFILE

1. LIFT-OFF
2. SRM BURN-OUT AND SEPARATION
3. CORE STAGE I BURN-OUT AND SEPARATION
4. INJECT INTO NOMINAL 140 BY 250 n. mi. ORBIT
5. SEPARATE CORE STAGE II
6. BURN OAS 13.7 min TO INJECT INTO A 250 BY 270 n. mi. TRANSFER ORBIT
7. CIRCULARIZE AT 270 n. mi. APOGEE BY BURNING OAS FOR 2.05 min

OFF-NOMINAL FLIGHT PROFILE

1. LIFT-OFF
2. SRM BURN-OUT AND SEPARATION
3. CORE STAGE I BURN-OUT AND SEPARATION
4. INJECT INTO OFF-NOMINAL 103 BY 317 n. mi. ORBIT
5. SEPARATE CORE STAGE II FROM OAS
6. BURN OAS 17.17 min TO INJECT INTO A 317 BY 270 n. mi. TRANSFER ORBIT
7. CIRCULARIZE AT 270 n. mi. PERIGEE WITH OAS DECELERATING BURN FOR 4.53 min

Figure III-2. Titan IIID/OAS injection profiles.

C. Tracking and Data Acquisition Network Analysis

Table III-4 shows the three prime network configurations in the MSFN unified S-band system which were selected for comparison, based on evaluation of the ground contact statistics and data processing capabilities. Each configuration was to meet the following demands:

TABLE III-4. CANDIDATE HEAO TRACKING NETWORKS

Network Configuration A		
Ascension Island (ACN)	Guam (GWM)	Texas (TEX)
Carnarvon (CRO)	Hawaii (HAW)	Santiago (SAN)
Canary Islands (CYI)		
Network Configuration B		
Canary Islands (CYI)	Hawaii (HAW)	
Guam (GWM)	Texas (TEX)	
Network Configuration C		
Ascension Island (ACN)	Guam (GWM)	
Canary Islands (CYI)	Hawaii (HAW)	

- Provide a minimum of one contact per orbit with a minimum time between contacts.
- Minimize number of remote tracking sites required.
- If possible, eliminate split recorder tape dumps in the event of station downtime or spacecraft communications failure.
- Minimize tape recorder constraints for data storage.
- Ensure complete transfer of all experiment and housekeeping data recorded.

Figure III-3 shows the HEAO-C orbital traces on a mercator projection for Network Configuration A. Although the ground track repeated at approximately 13 days, 70 revolutions were investigated to assure total coverage analysis.

An acceptable station contact time was defined as requiring a minimum of 5 minutes contact after allowing for land masking. A summary of comparative results for the three configurations is shown in Table III-5. HEAO-C records continuously in real time at maximum data input rate of 27.5 kilobits per second and dumps to the ground station at 500 kilobits per second. On-board data storage analysis assumed four tape recorders for simultaneous

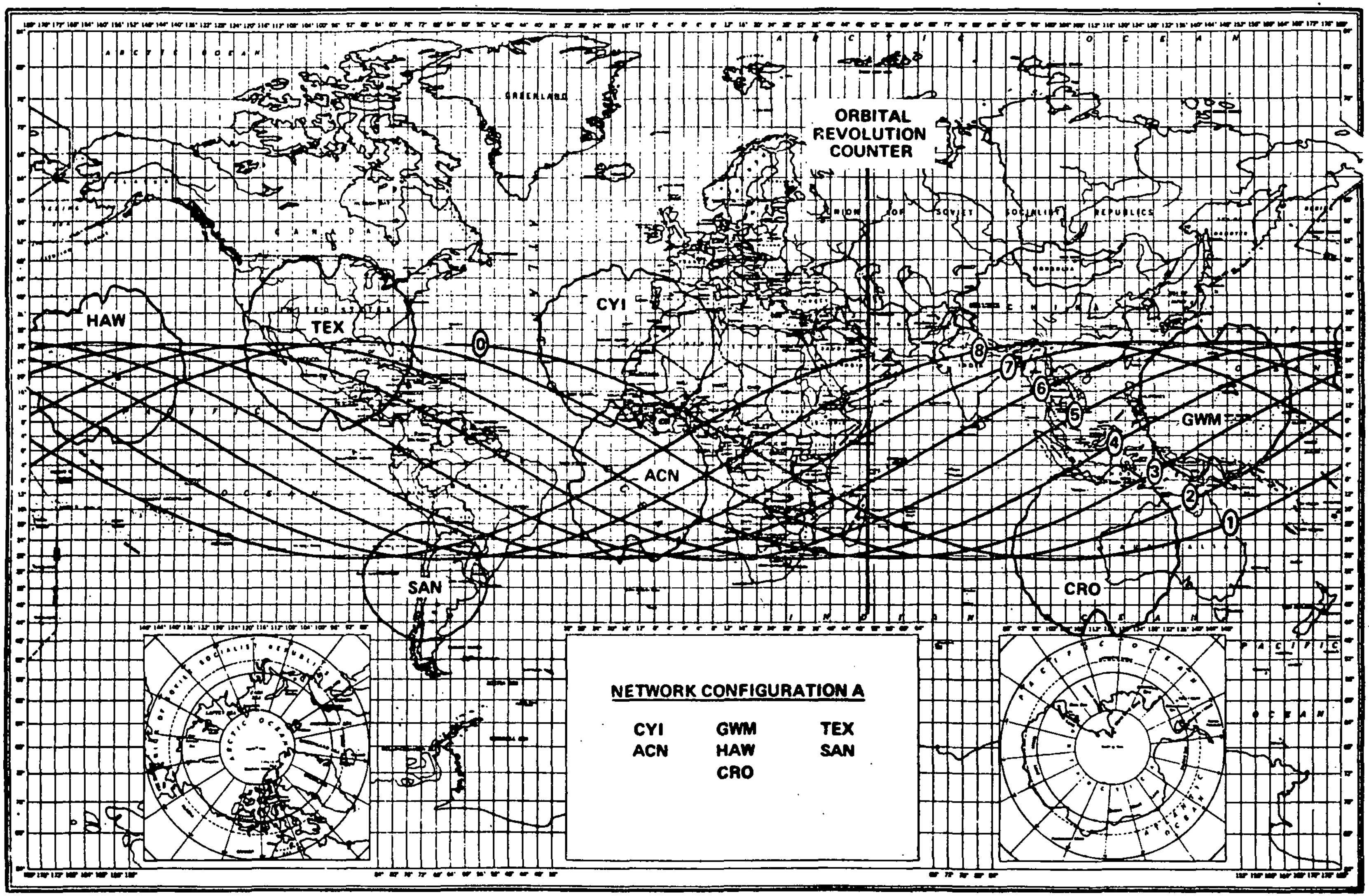


Figure III-3. Ground traces for Network Configuration A (H = 270 n. mi., i = 28.5 degrees).

TABLE III-5. MSFN COVERAGE SUMMARY (Orbital Count = 70 Revolutions, Altitude = 270 n. mi., Inclination = 28.5 degrees)

Tracking Data	Network Configuration		
	A	B	C
Total Contact Time (70 revs) (min)	2059.53	1376.30	1316.22
Number of Contacts	208	136	133
Percent of Contact Time	28.98	19.37	18.52
Average Contact Time Per Revolution (min)	29.27	19.51	18.65
Minimum Time of Contacts Per Revolution (min)	11.80	8.93	10.40
Average Number of Contacts Per Day	42	27	27
Minimum Number of Contacts Per Revolution	1	1	1
Number of Revolutions Without Contact	0	0	0
Maximum Gap Duration (min)	88.50	90.62	88.82
Average Gap (min)	24.35	42.39	43.81
Percent of Coverage Gap Less than 1 Hour Long	92.79	63.24	75.19
Maximum Peak of Data in Storage (Megabits)	164.615	165.255	165.904
Number of Peaks of Data in Storage	5	16	20
Maximum Time for Data Acquired and Dumped (min)	111.58	112.00	109.68

recording and reproducing; for the selected orbit a maximum of 167 megabits are recorded per revolution. Each network configuration provided sufficient contact time per orbit such that the peak onboard storage did not exceed 165 megabits and split dump was not required. In fact, the computer simulation showed that two tape recorders were probably adequate, although at least a third is required for contingency, such as station downtime. Any of the three network configurations would satisfy HEAO-C requirements.

D. Occultation and Source Viewing

Earth occultation of the sun is of primary concern to the design of the thermal control system, the solar arrays, and the attitude reference equipment. An investigation over the complete range of occultation parameters was made to determine the maximum and minimum occultation time per orbit. Results for the HEAO-C mission and selected orbit showed a maximum occultation time of 35.8 minutes and a minimum of 27.4 minutes.

Figure III-4 illustrates the viewing scheme and access bands, and Figure III-5 shows the viewing planes in the ecliptic coordinate system for the 15 degree half-cone angle about the earth-sun line. Objects with latitudes greater than 75 degrees can be seen any day during the year with the 15 degree offset. Not shown is the additional system capability for even larger offset angles (≈ 40 degrees continuous offset, well in excess of the time-limited 30 degree requirement) as well as the all-sky viewing capability when in the dark side of the orbit. After 43 days in orbit, HEAO-C will have had viewing access of the entire celestial sphere.

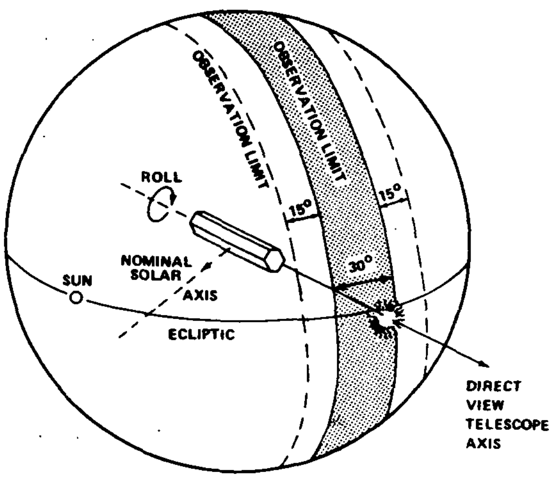


Figure III-4. Definition of ±15 degree and ±30 degree access bands.

E. Mission Timelines

Table III-6 shows a typical boost-to-orbit event sequence for the Titan III/OAS launch. The initial OAS burn shown in the injection profile (Fig. III-2) is replaced by two shorter burns which take place when in view of tracking stations.

Considerable effort was expended on detailing various on-orbit activities in order to establish spacecraft system design requirements. Known high energy sources were used to lend authenticity to the timelines. Of course, actual flight timelines will be determined on the basis of scientific return; it has been estimated that as many as 4000 new high energy sources might be discovered and mapped during the HEAO-A and -B missions.

Figure III-6 depicts a typical gross timeline for the 2 year mission. "Engineering" timelines contained include the following:

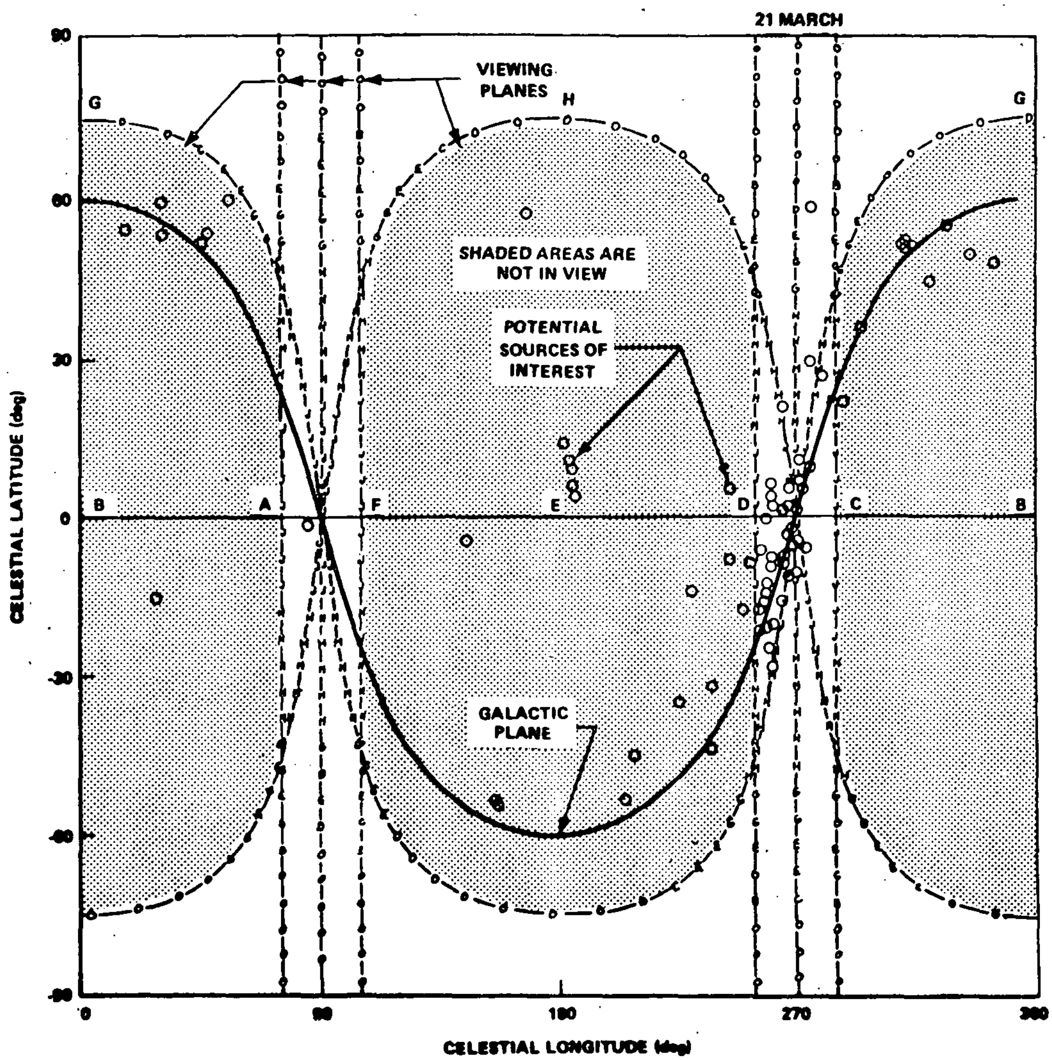


Figure III-5. Viewing planes in the ecliptic coordinate system.

- Normal Viewing Day
  - Viewing time — 67 percent (469 days)
  - Viewing method — 5 sources/day
  - Angular movement — Within ±15-degree band, total movement dictated by density of sources of interest

TABLE III-6. BOOST-TO-ORBIT SEQUENCE OF EVENTS (NOMINAL INJECTION PROFILE)

Time of Initiation Days:Hrs:Min:Sec	Event Duration Days:Hrs:Min:Sec	Event No.	Event
00:00:00:00		1	Ignite rocket motors.
00:00:01:48		2	Ignite Core Stage I.
00:00:02:02		3	Jettison solid rocket motors.
00:00:04:16		4	Separate Core Stage I/Ignite Core Stage II.
00:00:04:41	00:00:00:03	5	Jettison payload shroud.
00:00:04:44	00:00:02:49	6	Inject into a 140 by 250 nautical mile orbit and separate Core Stage II.
00:00:07:33	02:01:42:25	7	Coast in 140 by 250 nautical mile orbit/ Stabilize and rate damp spacecraft/Acquire Sun and deploy solar panel/Activate star trackers and obtain tracking star/Establish attitude reference alignment/Determine orbital parameters.
02:01:49:58	00:00:07:01	8	Inject into a 250 by 210 nautical mile orbit (over Carnarvon tracking station.
02:01:56:59	01:10:18:24	9	Coast in 250 by 210 nautical mile orbit for approximately 23 orbits.
03:12:13:23	00:00:06:24	10	Inject into a 250 by 270 nautical mile orbit (over Ascension Island tracking station).
03:12:19:47	00:10:29:57	11	Coast in 250 by 270 nautical mile orbit for approximately seven revolutions.
03:22:49:44	00:00:02:01	12	Circularize 250 by 270 nautical-mile orbit into 270 nautical mile orbit (over Ascension tracking station).
03:22:51:45	00:01:34:00	13	Coast in 270 nautical mile orbit for approximately one revolution/Typically begin earth occultation for this orbit. Earth occultation will reoccur and terminate in intervals of 94 minutes and 37 minutes, respectively, from this time. The 94 minutes is the period of a 270 nautical mile orbit.
04:00:25:45	00:04:00:00	14	Turn on CMGs.
04:04:25:45	00:01:34:00	15	Establish attitude reference alignment.
04:05:59:45	07:00:00:00	16	Acquire x-ray source for subsystems and experiment checkout and calibration/Checkout and calibrate experiments.

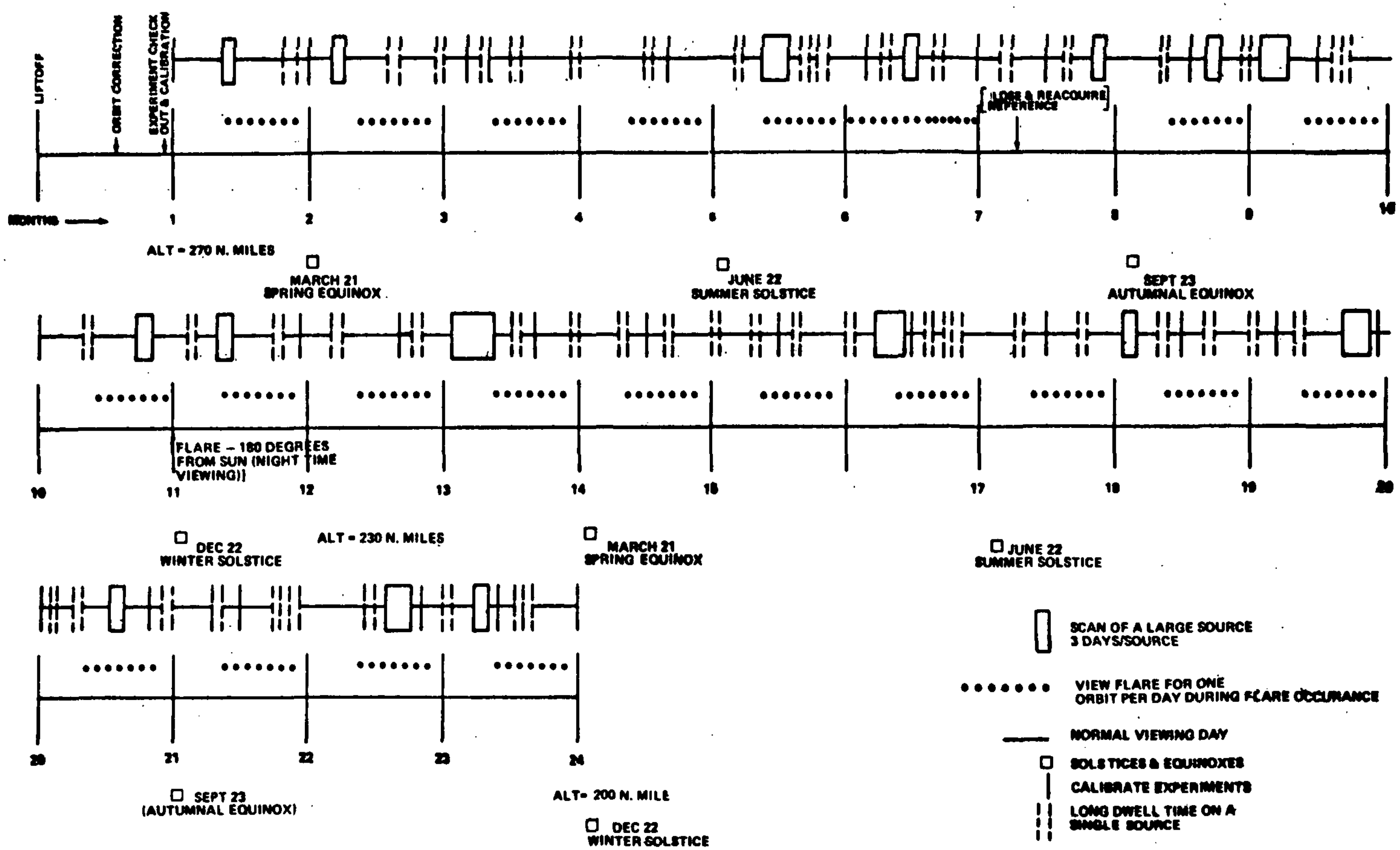


Figure III-6. Typical gross timeline for 2 year HEAO-C mission.

- Scan of a Large Source

  - Viewing time — 10 percent (70 days)
  - Viewing method — 1 point/day, 3 days/source
  - Angular movement — 2 arc min/day

- Long Dwell Time on a Single Source

  - Viewing time — 15 percent (105 days)
  - Viewing method — 2 days/source
  - Angular movement — 0 degrees/day

- Flare Observation Between ±15 Degree and ±30 Degree Band

  - Viewing time — 4 percent (28 days)
  - Viewing method — View for one orbit per day
  - Angular movement — As required

- Flare Observation (Antisolar Viewing)

  - Absolute viewing — 1 percent (7 days)
  - Viewing method — View flare during dark period of orbit
  - Angular movement — As required

- Calibration of Experiments (Monthly)

  - Absolute viewing — 3 percent (21 days)
  - Viewing method — 1 day
  - Angular movement — 0 degrees after source is locked onto by instruments

- Loss of Reference

  - Absolute viewing — As required
  - Viewing method — Spacecraft will reacquire sun in an "emergency sun acquisition mode" and then rotate about solar axis until source is located
  - Angular movement — As required

All activities represented on the gross timeline are structured relative to their duration and occurrence. Normal viewing days which have

been projected to comprise 67 percent of total mission time are represented by a horizontal bar in Figure III-6.

Figure III-7 depicts a timeline for a typical, normal viewing day and shows how the various experiments might time-share the telescope focal plane.

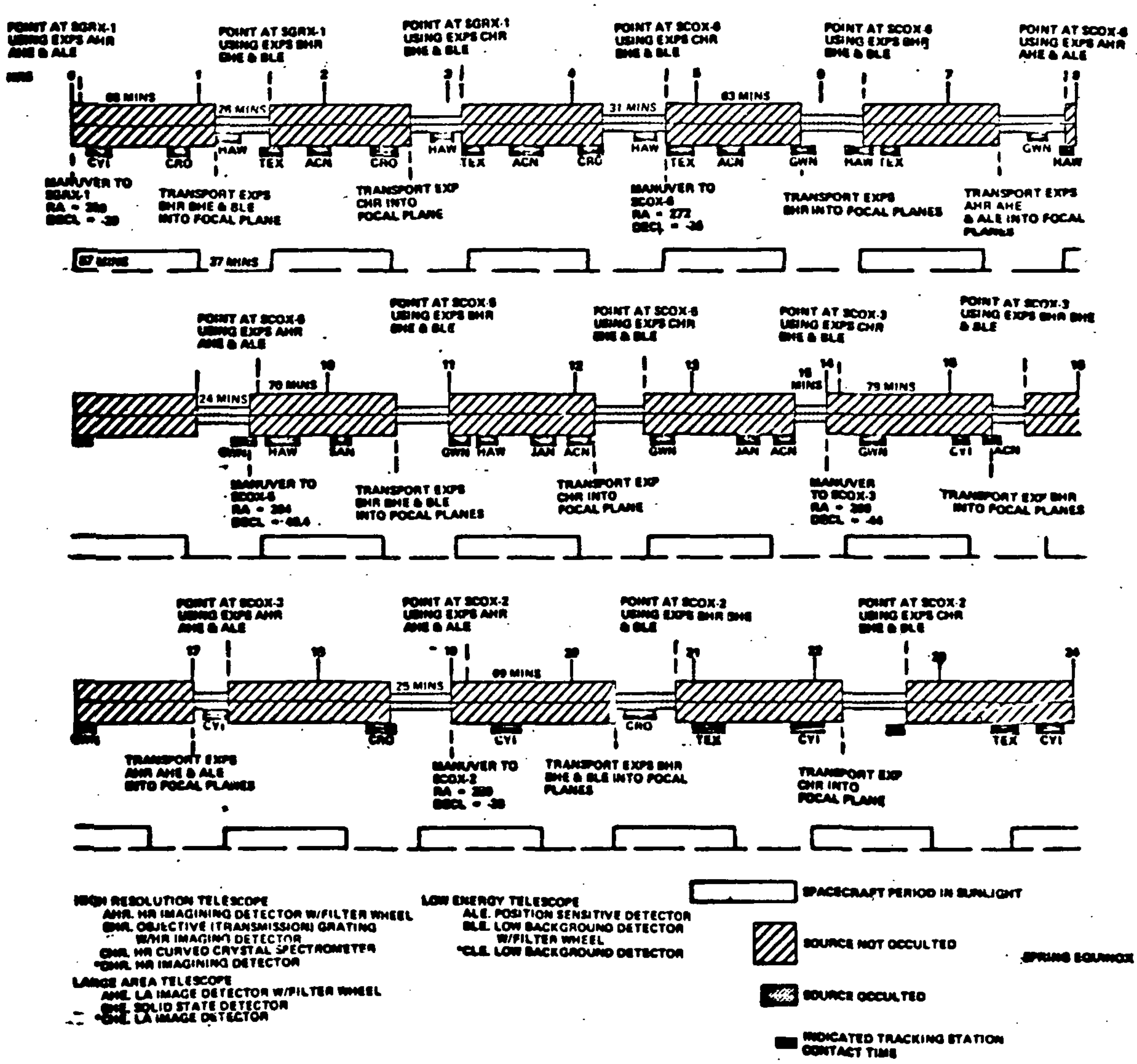


Figure III-7. Typical engineering timeline for normal viewing day.

CHAPTER IV. OBSERVATORY DESIGN

The principal design goal for the HEAO-C spacecraft was to maximize commonality with the HEAO-A/B spacecraft in order to minimize cost of new development. Divergence from commonality was justified on the basis of differing mission and experiment requirements or improvement in cost-effectiveness. Study concurrent with the Phase B definition of the HEAO-A/B spacecraft resulted in a design concept which achieved this commonality goal.

The following description of the Observatory configuration and overall design features, as well as the subsystems' descriptions in Chapter V of this summary, pertains to the Phase A "baseline" concept. Numerous alternative configurations were developed during the course of the study, including alternative configurations for both baseline and alternative experiment complements, and are presented in Volume III of this report.

A. Baseline Configuration

A layout of the baseline Observatory configuration is shown in Figure IV-1. The layout is keyed to the Master Equipment List for identification of the components.

The Observatory has a 105 inch maximum outside diameter and is 360 inches long (excluding the sunshade, OAS, and adapter). The sunshade length is 58 inches, the spacecraft/OAS adapter length is 12.5 inches, the OAS length is 62.25 inches, and the OAS engine nozzle extends another 34.5 inches. Total length of the Observatory orbital configuration from sunshade tip to nozzle exit plane is 514.75 inches (42.9 feet). Maximum OAS diameter is 120 inches (10 feet). The cross section of the outer spacecraft structure is octagonal, and one corner of the octagon is pointed toward the sun during normal operation.

Foldout solar array panels along two sides of the octagon provide most of the power, with body-mounted panels on the two sides nearest the sunline providing the remaining power and providing room for growth. The foldout panels can be identical to those on HEAO-A and -B spacecraft, although the hinge attach points on the spacecraft are different. The use of foldout panels rather than body-mounted panels allows the array to operate at a lower, more efficient temperature, with only a minimal increase in orbital drag.

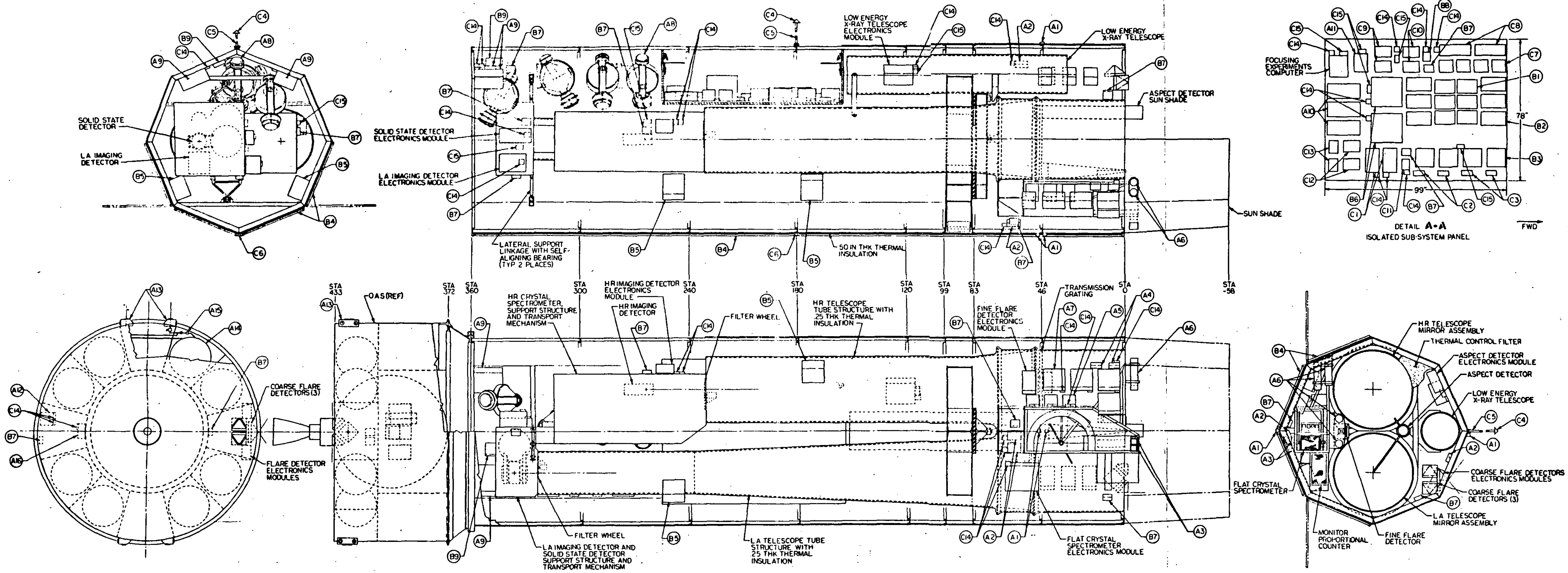


Figure IV-1. Baseline HEAO-C Observatory.

Identification Number	System/Component	No. Used	No. Required	Unit Power (W)	Operating Time	Power Required (W)	Size (in.) L × W × H	Total Volume (in.^{3})	Unit Weight (lb)	Total Weight (lb)	Operating Temperature Limits (°F)	Remarks
	Attitude Sensing and Control											
A1	WASS[a]	3	2	0.0	Continuous	0.0	2 × 1.9 × 2	23	1.0	3	-120 to 130	b
A2	WASS Electronics	3	1	0.4	Continuous	0.4	5 × 7 × 2	210	1.0	3	-4 to 122	b
A3	DSS[c]	2	1	0.0	Continuous	0.0	3.8 × 3.8 × 1.5	434	0.75	1.5	-4 to 130	b
A4	DSS Electronics	2	1	1.7	Continuous	1.7	7.8 × 5 × 2.5	98	2.5	5	-4 to 130	b
A5	Gyro Package (2/pkg)	3	3 (1/pkg)	15.0	Continuous	45.0	7 × 8 × 6	1 008	11.0	33	32 to 130	d
A6	FHST[e]	4	2	0.0	Continuous	0.0	15 L × 4 Dia.	756	9.0	36	-4 to 130	f
A7	Star Tracker Electronics	4	2	8.0	Continuous	16.0	5 × 11 × 12	2 640	14.0	56	TBD[i]	f
A8	CMG[g]	4	4	9 operating 32 spinup	Continuous	36.0	32 × 19 × 9	21 888	135.0	540	-22 to 140	b
A9	CMG Electronics	4	4	18.0	Continuous	72.0	12 × 16 × 7	5 376	27.0	108	-4 to 130	b
A10	Digital Processor	3	1	65.0	Continuous	65.0	18.5 × 5 × 8	740	20.0	60	0 to 130	b
A11	Transfer Assembly	1	1	5.0	Continuous	5.0	5 × 7 × 10	350	10.0	10	0 to 130	b
A12	RCS[h] Electronics	1	1	11.0	Continuous	11.0	9 × 14 × 7	1 784	16.0	16.0	-4 to 120	b
A13	Thruster Module	4	4	4.5	2 Percent	20.6	6 × 7 × 11	1 848	9.0	36	TBD	
A14	RCS Tank	8	8	6.12	TBD	5.2	22 Dia.	45 000	17.2	138	TBD	
A15	Other RCS Items	N/A	N/A		N/A	16.1	N/A	N/A		33	TBD	
A16	OAS[j] Electronics	1	1	9.0	Orbital Adjust	9.0	7 × 8 × 4	224	TBD	TBD	TBD	
	Electrical Power											
B1	Batteries	6	6	N/A[k]	Continuous	N/A	13.1 × 6.67 × 7.4	3 880	56.0	336	40 to 60	l
B2	Chargers	6	6	N/A	Continuous	N/A	11 × 8 × 6	3 168	14.0	84	- 40 to 140	f
B3	Regulators	4	2	N/A	Continuous	N/A	11 × 8 × 5	1 760	8.0	32	- 40 to 140	f
B4	Solar Array	1	1	N/A	Continuous	N/A	240 ft^2		1.1 lb/ft^2	264	- 40 to 212	b
B5	Solar Power Distribution	2	2	N/A	Continuous	N/A	13 × 11.5 × 6.75	2 018	18.0	36	- 40 to 140	b
B6	Power Control Unit	2	2	N/A	Continuous	N/A	14 × 8 × 8	1 792	16.0	32	- 40 to 140	f
B7	EIA[m]	10	10	1.0	Continuous	10	5 × 4 × 3	600	2.5	25	- 40 to 140	b
B8	Thermal Control Unit	1	1	TBD	Continuous	TBD	TBD	TBD	TBD	TBD	TBD	
B9	Cable Interface Unit	1	1	N/A	Continuous	N/A	9 × 6 × 2	108	8.0	8	N/A	
	Communication and Data Handling											
C1	Dual Transponder	2	2				13 × 8 × 6	1 248	23.3	47	32 to 130	d
	Receivers	4	4	3.5	Continuous	14.0						
	Transmitter	4	2	21.0	5 Percent	2.0						
C2	PSK[n] Demodulator	2	2	0.4	Continuous	4.0	1.3 × 2.8 × 6	44	2.0	4	32 to 130	d
C3	Frequency MUX	2	2	2.0	Continuous	0.8	7.25 × 5.0 × 1.6	116	2.0	4	32 to 130	d
C4	Antenna, Conical	1	1		Continuous		Base 12, 12 L		3.0	3	TBD	d
C5	Boom	1	1		Continuous	10.0	1.5 Dia., 72 L		1.0	1	TBD	d
C6	Antenna, Flat Spiral	1	1		Continuous				1.0	1	TBD	d
C7	Tape Recorders	4	1 Rec. 1 P/B	10 Rec. 20 P/B	Continuous 5 Percent	10.0 1.0	9 × 7.25 × 5.75	1 501	15.0	60	14 to 120	b/d
C8	Tape Recorder Control Unit	1	1	1.0	Continuous	1.0	6 × 7.3 × 1.6	700	3.0	3	32 to 130	b
C9	PCM[o] Encoder	2	2	3.2	Continuous	6.4	6 × 9 × 2.8	302	4.0	8	32 to 130	b
C10	Format Generator	2	2	2.1	Continuous	4.2	6 × 9 × 2.8	302	4.0	8	32 to 130	l
C11	Clock	1	1	14.0	Continuous	14.0	6 × 3 × 3	54	3.0	3	32 to 130	l
C12	CMD[p] Processor	2	2	7.8	Continuous	15.6	6 × 9 × 2.8	302	2.0	4	32 to 130	l
C13	CMD Memory	2	2	3.5	Continuous (Unit 2: 5 Percent)	3.7	6.2 × 7 × 4.1	356	6.0	12	-22 to 140	l
C14	RAU or RMU	40	1	1.2	Continuous	1.2	2.8 × 2.8 × 1	312	0.3	12	- 22 to 140	b
C15	RCU or RDU	8	1	1.4	Continuous	1.4	6 × 9 × 2.8	2 416	1.0	8	- 22 to 140	b

a. Wide angle sun sensor
b. Component selected for HEAO-A/B by GAC in Phase B study
c. Digital sun sensor
d. Component selected for HEAO-A/B by TRW in Phase B study
e. Fixed head star tracker
f. Component exists from other programs but not proposed for HEAO-A/B
g. Control moment gyro
h. Reaction control system
i. To be determined
j. Orbit adjust stage
k. Electrical power system components not considered to consume load power
l. New design required for HEAO-C
m. Electrical integration assembly
n. Phase shift keyed
o. Pulse code modulator
p. Command

Master Equipment List

The OAS and its adapter remain attached to the rest of the spacecraft throughout the mission. (This decision was made late in the study, so as to be commensurate with a similar decision which was made late in the HEAO-A and -B Phase B study.) The RCS tanks, thrusters, lines, valves, etc., and three coarse flare detectors are located in the OAS.

A sunshade is provided to give thermal protection to experiments when the spacecraft pointing axis is tilted toward the sun (as much as 30 degrees) and/or when the spacecraft is rolled about the pointing axis (as much as 15 degrees). The sunshade and its worst-case shadow line are shown in Figure IV-2.

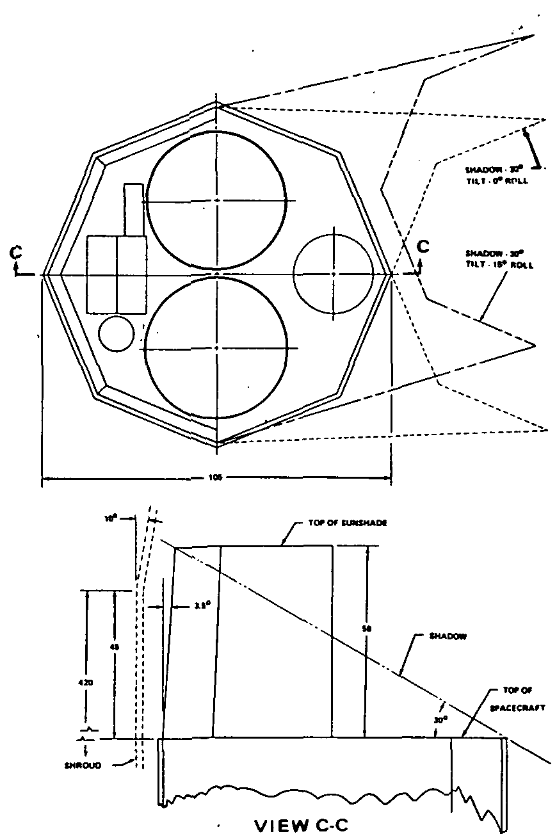


Figure IV-2. HEAO-C sunshade.

Alignment and pointing accuracy are the most critical design requirements and, as such, strongly influence the structural and thermal control concepts. The baseline design contains a dual structure arrangement. The outer structure supports the inner structure (on which all experiments are mounted) and the subsystems. To prevent high temperatures inside the Observatory and to prevent large temperature gradients across the outer structure, 0.5 inch of multilayer aluminized mylar insulation is wrapped around the outer structure, with alzak skin mounted on standoff insulators external to the insulation and spaced from it about 0.2 inch. Multilayer insulation is judiciously applied to parts of the experiments to further control their environments. An aluminized polypropylene membrane covers the entire pointing end of the Observatory except for the view faces of the experiments and star trackers. Most of the subsystems are located on the antisolar side of the spacecraft to facilitate thermal control by utilizing the uninsulated thermally stable exterior surface.

The telescope tubes and the attached forward beam assembly which supports the miscellaneous experiments and the alignment-critical attitude

sensors (star trackers, rate gyros, and digital sun sensors) comprise an optical bench. The optical bench is attached to the main Observatory structure by means of two forward ball joints and two aft linkages (Fig. IV-3). The two large telescope tubes are attached at the upper ends to the circular rings around each mirror frame. The rings are bolted to the deep oval frame around the two tubes. A cross beam at the middle of the oval frame is used to transmit the total load through a ball joint to another beam which then distributes the load to rubber pads. The ball joint is used to isolate the thermal bending of the outer shell from the tubes. These two tubes are rigidly joined at the aft end. The large area (LA) telescope tube is attached to the outer structure by two delta-frames, using self-aligning bearings, to take out lateral and torsional launch loads and to stabilize the aft end of the telescopes during slew maneuvers in orbit. The delta frames have self-aligning bearings on each end so that thermal deformation of the outer Observatory structure, even at an unusual off-sun angle, does not induce a stress into the optical bench.

The forward end of the low energy (LE) telescope is attached through its own ball joint to the same beam which supports the two large telescopes. The aft end of the LE telescope tube is linked to the large telescopes by an A-frame-and-strut, using self-aligning bearings and pins, to maintain alignment between the telescopes.

Shock mount pads are provided between the ball joint sockets and the crowfoot beam assembly to give protection from vibration to the optical bench during the Titan launch. Three rubber pads are utilized and are mounted atop the crowfoot beam assembly which distributes optical bench loads to the outer structure.

The large telescope tubes are fabricated of graphite-epoxy, primarily because of the excellent thermal properties of that material. The deep oval ring which ties the large telescopes together is made of titanium for low thermal conductivity. All other structure is aluminum.

The structural concept of ball joints, shock mounts, and linkages offers several advantages. First, bending forces are not introduced into the optical bench; outer structure deformation does not affect Observatory operation. Second, the optical bench is thermally isolated from both outer structure and, via the ball joints and shock mounts, from the crowfoot beam. Third, coalignment among the telescopes, sensors, and ancillary experiments is more easily achieved and maintained.

Employment of a separate tube for each telescope provides several advantages over other concepts which were considered. Among these are (1)

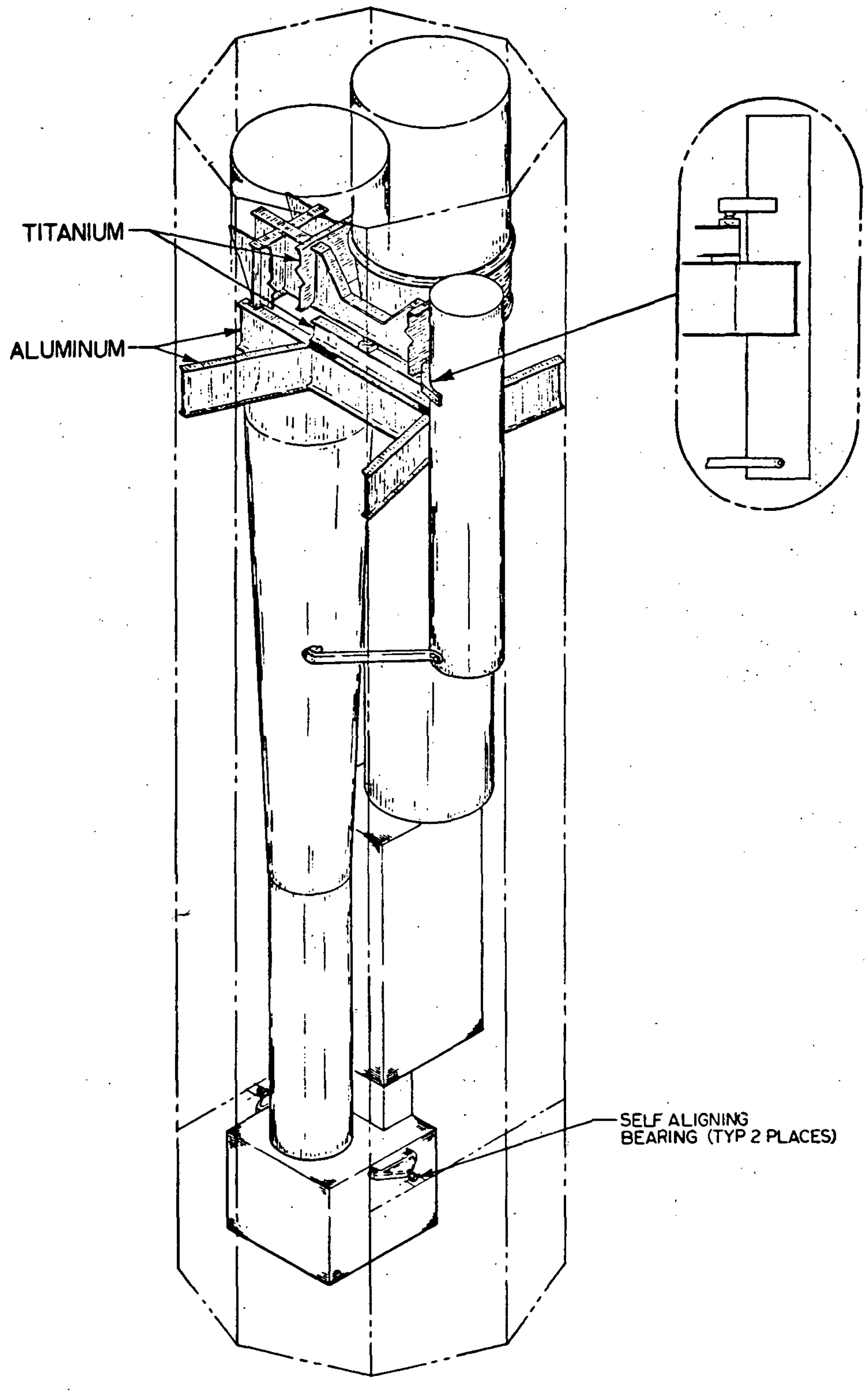


Figure IV-3. Internal support structural arrangement.

simplification of structural and thermal interfaces among telescopes and simplification of integration and development since each telescope may be designed, built, and tested as an entity before integration into the Observatory; (2) greater programmatic flexibility to accommodate schedule changes and development problems, (3) insensitivity to changes in design in other telescopes or Observatory systems; (4) greater availability of space in the Observatory for packaging subsystems; and (5) greater structural efficiency.

For ease of manufacturing and assembly, the spacecraft outer structure might be assembled into two longitudinal halves, with telescopes mounted prior to joining the halves (Fig. IV-4). Disassembly could be accomplished in the same fashion should removal of telescopes be required. Routine access to the interior for maintenance and testing could be accomplished by using uninsulated removable panels on the anti-solar side and by entering through the ends of the Observatory with appropriate access equipment.

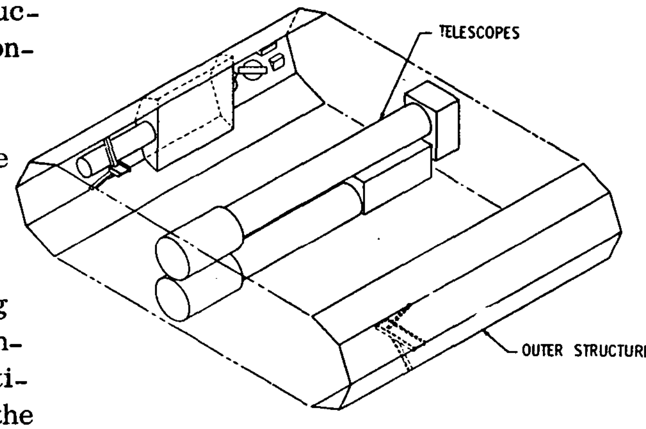


Figure IV-4. Possible HEAO-C assembly scheme.

Figure IV-5 is a block diagram showing the baseline Observatory systems and subsystems, and Figure IV-6 is a schematic diagram depicting the experiment mounting scheme.

B. Design Characteristics

1. Electrical Power. A summary of Observatory power requirements is shown in Table IV-1 for normal on-orbit viewing operations. HEAO-C power requirements are greater than those defined for HEAO-A and -B in the Phase B studies, approximately 640 watts for those missions if CMGs are used, including 20 percent contingency, compared to 722 watts for HEAO-C. (The 14 percent contingency shown in Table IV-1 resulted from growth of power requirements during the Phase A analysis; a 20 percent contingency is recommended for follow-on Phase B effort.)

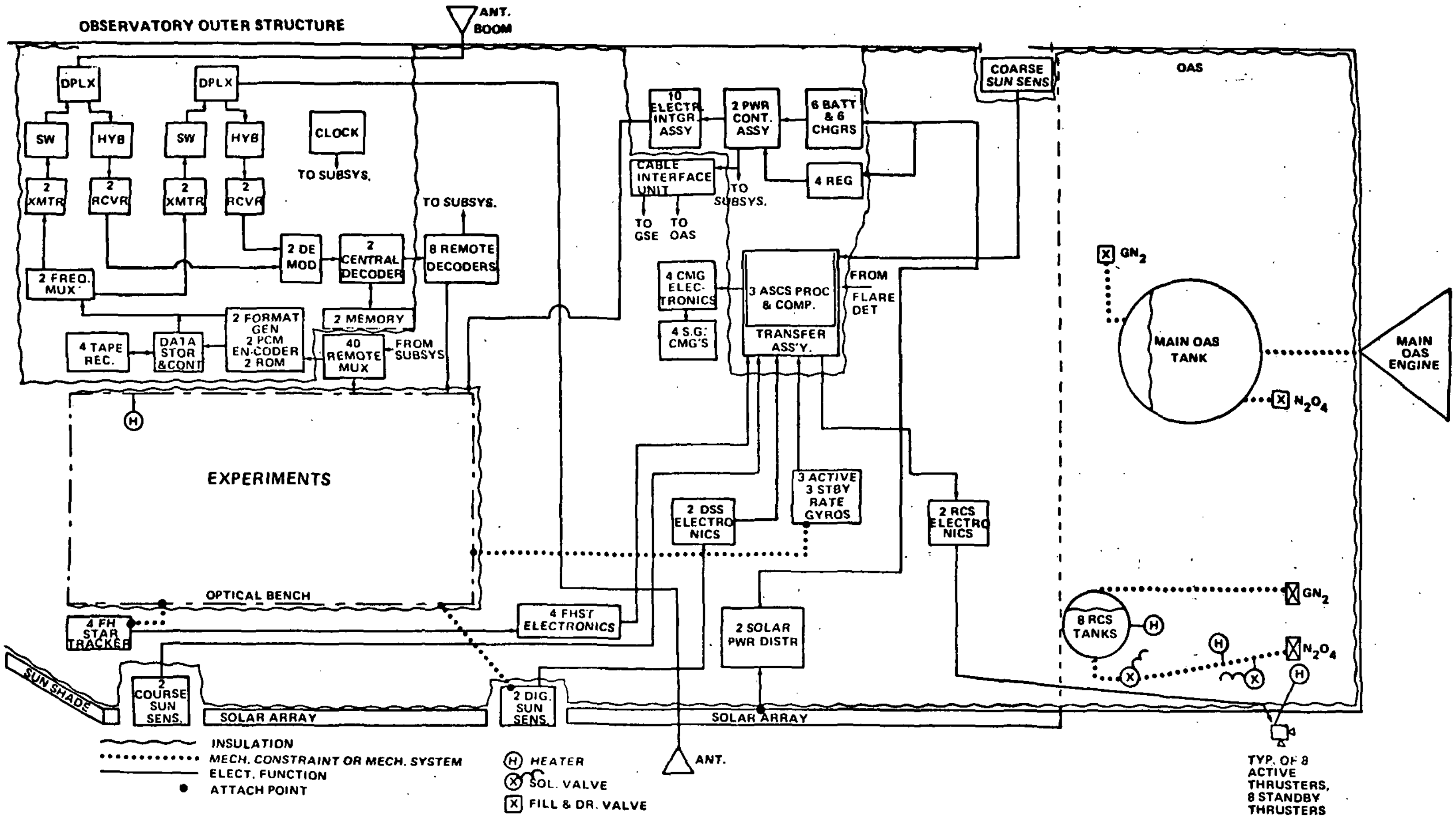


Figure IV-5. Baseline Observatory systems.

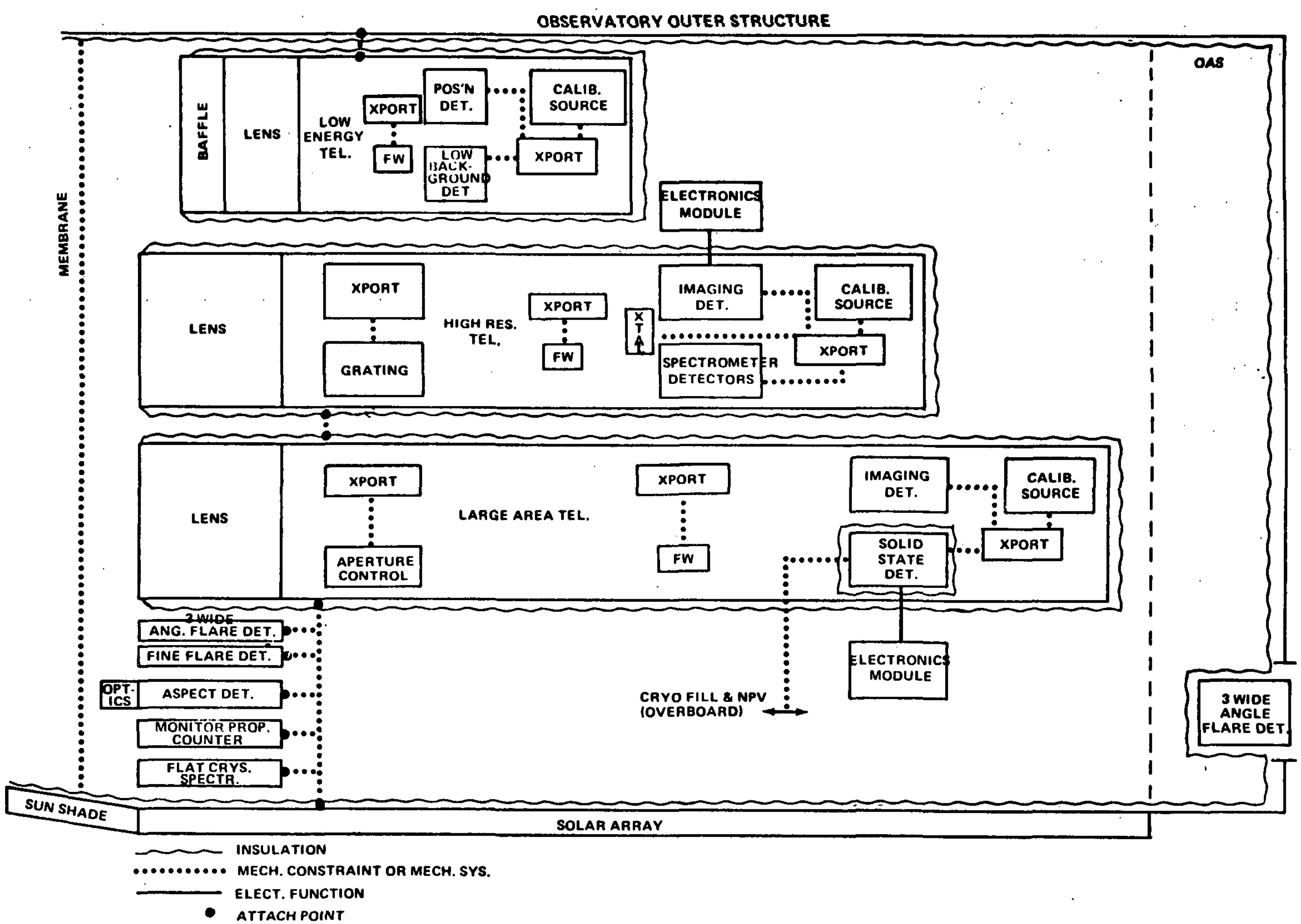


Figure IV-6. Baseline experiment mounting scheme.

TABLE IV-1. HEAO-C ON-ORBIT ELECTRICAL LOAD SUMMARY

Load	Average Power (W)	Peak Power (W)
Experiments	234.0	294
Communications and Data Handling	79.3	141.6
Attitude Sensing and Control	252.1	353.1[a]
Experiment Thermal Control[b]	10.0	40.0
RCS	41.9	295
Electrical System	16.0	25.0
Baseline Total	633.3	1148.7
Contingency (~14%)	89.0	89.0
Total Design Load	722.3	1237.7

a. Assumes simultaneous spinup of all CMGs.
b. All other thermal control power is listed under the applicable systems.

2. Physical Characteristics. Table IV-2 summarizes the HEAO-C baseline weights and Table IV-3 summarizes the mass characteristics. The in-orbit weight of the HEAO-C at start of mission (excluding the weight of the OAS and nonjettison portion of the Titan adapter) is 14 353 pounds, or approximately 4650 pounds less than the comparable HEAO-A configuration developed during the Phase B studies. The lower HEAO-C weight results primarily from a lighter experiment package, approximately 7600 pounds (including telescope tubes) as against the HEAO-A 12 500 pounds. A 20 percent contingency is suggested for the HEAO-C control weight during the next phase of study, for an Observatory orbital weight of 18 700 pounds.

3. Reliability. Table IV-4 presents the spacecraft reliability numerics; the experiments are not included. Alternates to improve the baseline reliability were studied and additional costs and testing identified (see Volume III, Appendix G). Unlike the HEAO-A and -B missions which have a two year operational goal but a one year required lifetime and reliability specification, HEAO-C guidelines included a firm requirement for two years. After considerable analysis and several discussions with Principal Investigators, a conclusion was reached, and offered here as a recommendation, that reliability and lifetime requirements should be identical for HEAO-A, -B, and -C. Such a philosophy would permit maximum cost-effectiveness through commonality across all missions by avoiding additional qualification and/or requalification requirements, additional testing complexity associated with greater redundancy, and possible component modification and redesign.

TABLE IV-2. HEAO-C BASELINE OBSERVATORY WEIGHT SUMMARY

Experiments			7 175
HR Telescope (less tube)		2636	
Mirrors	2025		
Detectors and Misc.	611		
LA Telescope (less tube)		2820	
Mirrors	2400		
Detectors and Misc.	420		
LE Telescope		840	
Mirrors	400		
Detectors and Misc.	140		
Structure (tube)	300		
Miscellaneous Experiments		879	
Aspect Detector	121		
Flare Detectors	297		
Monitor Proportional Counter	142		
Flat Crystal Spectrometer	162		
Cabling	157		
Subsystems			6 966
Structure		3375	
Outer Shell (including sunshade)	1417		
Bench (tubes and mounts)	1497		
Crowfoot Beam Assembly	261		
Mounting Brackets	200		
Attitude Sensing and Control		1927	
Attitude Sensing	138		
Attitude Control	734		
RCS (dry)	207		
Propellant and Pressurant	848		
Thermal Control		505	
Insulation	120		
Coatings	70		
Alzak Skin	300		
Heaters	15		
Communication and Data Handling		178	
Communication	60		
Data Handling	118		
Electrical Power		856	
Arrays	332		
Storage	396		
Regulation and Control	32		
Distribution	96		
Cables		125	
Miscellaneous			
OAS (stripped)			1 223
OAS Propellant			1 240
Spacecraft Adapter			212
Titan Adapter (212 Drop Weight)			221
Observatory Lift-off Weight			17 037
Observatory Weight After Titan Separation			16 825
Observatory Weight After Final Orbit Circularization			15 585[a]

a. Updated weight for OAS is 1499.2 pounds and 97.6 pounds for nonjettison shroud. HEAO-C orbital configuration at BOM becomes 15 959 pounds.

TABLE IV-3. BASELINE MASS CHARACTERISTICS SUMMARY

Configuration	Weight (lb)	Torque Arm, TA (in.)	Centroidal Inertia (slugs-ft^2 × 10^3)		
			I_x	I_y	I_z
Baseline plus OAS	15 585	250	2.88	69.51	70.05
Baseline plus 25%	19 481	249	3.46	77.48	78.01
Baseline plus 50%	23 378	235	3.75	97.14	98.00

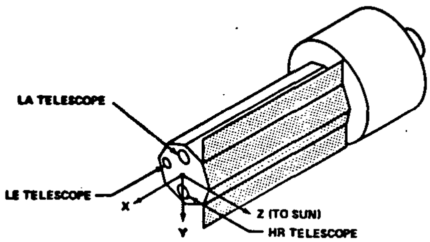


TABLE IV-4. HEAO-C RELIABILITY NUMERICS SUMMARY

Subsystem	Reliability 1 yr	Reliability 2 yr
Attitude Sensing and Control	0.94520	0.81024
Electrical Power (EPS)	0.99199	0.94403
Communications (COMM)	0.99963	0.99792
Data Handling (DHS)	0.98890	0.95895
Reaction Control	0.99739	0.92948
Baseline	0.92446	0.68035
Alternate 1	0.96188	0.76363
Alternate 2	0.96717	0.83899

Several factors concerning the two year, high reliability mission must be considered:

- Experiments must be designed with a two year lifetime and a high second year reliability. Indications are that the PIs may prefer a lower reliability requirement for the second year, due to complexity and cost.

- Priority for utilization of the tracking network has traditionally decreased as time in orbit increases. If there is a great demand for the network from many spacecraft, there will be greater probability of losing HEAO data later in the mission. Hence, there may be less return on the investment in the second year lifetime and high, second year reliability.

- Using a mission/data worth model which decreases with time in orbit (Fig. IV-7), the value of the data and the mission appears less for the second year; hence, from this viewpoint also, the return on the investment in the second year lifetime and high, second year reliability might be less.

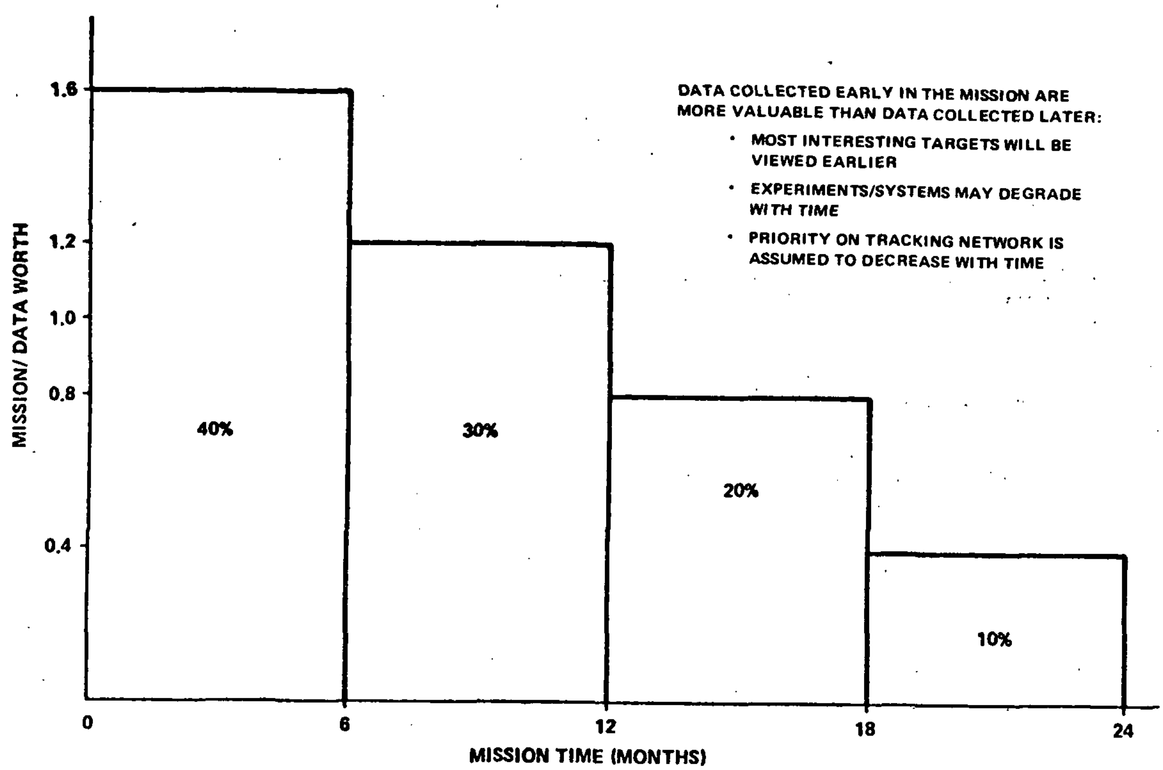


Figure IV-7. A possible mission/data worth model.

4. Performance Capability. Table IV-5 lists key design requirements and associated design features and performance capability.

TABLE IV-5. SIGNIFICANT HEAO-C DESIGN CHARACTERISTICS

Design Required or Driver	Design Feature	Performance Capability
Pointing Accuracy: ±1 arc min	CMGs	±1/2 arc min
Pointing Stability: Good	CMGs	≈ 2 to 5 arc sec per 1/2 orbit
Jitter Rate: 1 arc sec/sec	CMGs	< 1 arc sec/sec
No. of Maneuvers: > 3600	CMGs	> 3600
Experiment Coalignment: ±1 arc min	Tight thermal control, minimum structural shifts and deformations, optical bench with ball and linkage mounting	< ±1 arc min coalignment, max ΔT of ±1° F across tube, max ΔT of ±5° F along tube, max ΔT of ±2.5° F across outer structure
Exp. Vibration Limits: < Titan Levels	Shock-mounting of experiments	Undetermined
Exp. and Optical Surface Sensitivity: Critical	Remote thruster location, elimination of consideration of some propellants	Undetermined
No. of Detectors per Telescope: Multiple	Exp. transport mech.	Adjustment in ±Z and ±X directions to > 0.001 in. accuracy
Telescope Sensitivity Degradation: Minimum	Exp. transport mech.	Same
Exp. Calibration with Onboard Source (Partly)	Exp. transport mech.	Same
Power: 722 W Plus Growth Capability	Foldout arrays	857 W EOM 15 deg off-sun
Off-sun Pointing: 15 deg Continuously at End of Life	Foldout arrays	≈ 40 deg off-sun continuously at end of life
Data Recording Rate: 27.5 kbs	Onboard data compression/processing (experimenter-supplied computer) to decrease from data rate of > 50 kbs	27.5 kbs
Sequential Pointing Without Frequent Ground Contact	Command Storage	24 hr command storage
No. of Commands: 767	10 bit command data word	1124 commands
Launch Date: 1976-77	270 n. mi. orbit	>2 yr
Lifetime: 2 yr	Redundancy and high failure condition operation	> 2 yr
Reliability: 0.95 for 1 yr (up to 0.9 for 2 yr)	Redundancy and high failure condition operation	0.924 for 1 yr (0.680 for 2 yr)

C. Telescope Alignment and Operation

Conceptual designs of experiment transport mechanisms for the two large telescopes are shown in Figures IV-8 and IV-9. These devices position the various experiments in and out of the focal region; they also provide a capability for in-orbit adjustment to help maintain precision alignment and pointing. The mechanisms are mounted directly to the telescope tubes and are contained in thermally insulated housings.

The baseline HEAO-C spacecraft includes three X-ray grazing-incidence telescopes and several corollary viewing experiments that do not utilize the telescope optics. Maximum data return can be achieved if all experiment viewing axes are nearly parallel so that all telescopes and corollary experiments may view the same X-ray source simultaneously. To achieve simultaneous viewing, the optical axes of three telescopes and the corollary experiments must be aligned to a common pointing axis (coaligned). The proper positioning of this pointing axis by the spacecraft attitude control system will then permit simultaneous viewing of the X-ray source.

Coalignment of the experiments was considered to be one of the strongest design drivers during the study and, consequently, the Observatory design has some margin in this area. However, the effect of misalignments greater than those allowed would not be a catastrophic failure but, rather, a degradation in performance in the area of either decreased sensitivity of individual experiments, decreased ability to make simultaneous temporal measurements of a source using several experiments, or increased time required to make measurements. In general, a choice could be made as to which of the foregoing types of degraded performance would be most acceptable by selecting the pointing axis to be at the centroid of the experiment optical axes, selecting it to be coaxial with one of the experiments, or shifting the detector(s) with the focal plane transport mechanisms.

The coalignment requirement is that all optical axes be aligned within 1.0 arc minute of each other. The 2 axis pointing requirement for the pointing (reference) axis is ±1.0 arc minute. These conditions are illustrated for three telescope axes in Figure IV-10 where the angle between each pair of telescope axes is 1 arc minute; the pointing axis in this illustration is the centroid of the triangle formed by joining the telescope axes. If there is a shift of telescope axes during launch, or in orbit, it might be desirable to move the location of the pointing axis. This could be accomplished in orbit by software changes in the onboard attitude control processor.

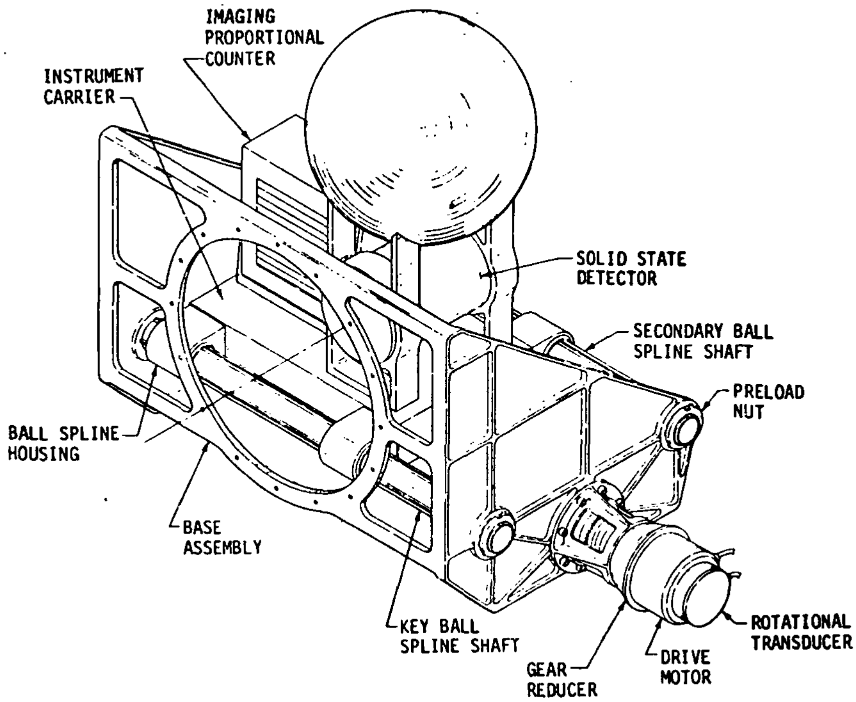


Figure IV-8. LA telescope transport mechanism isometric.

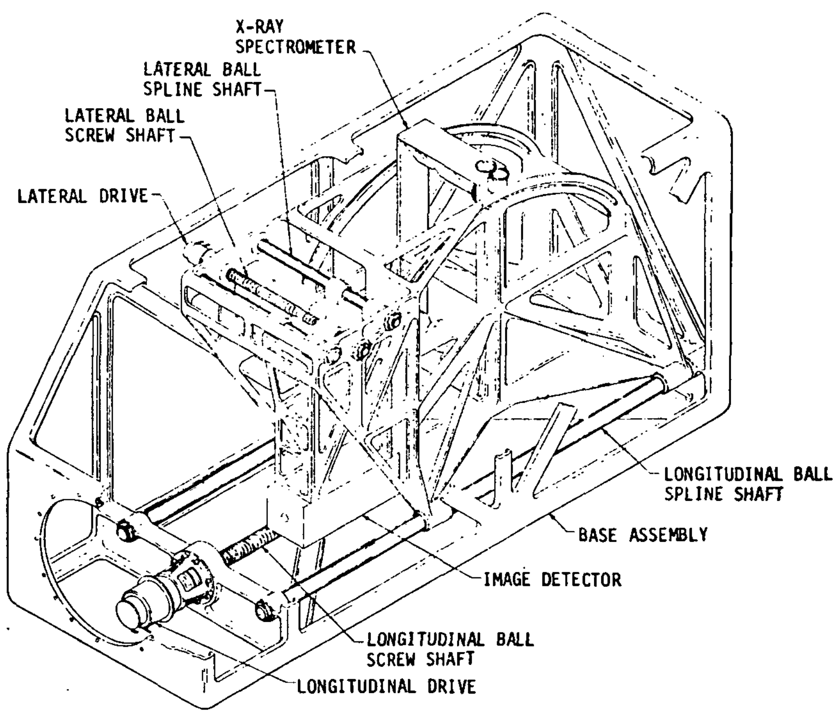


Figure IV-9. HR telescope transport mechanism.

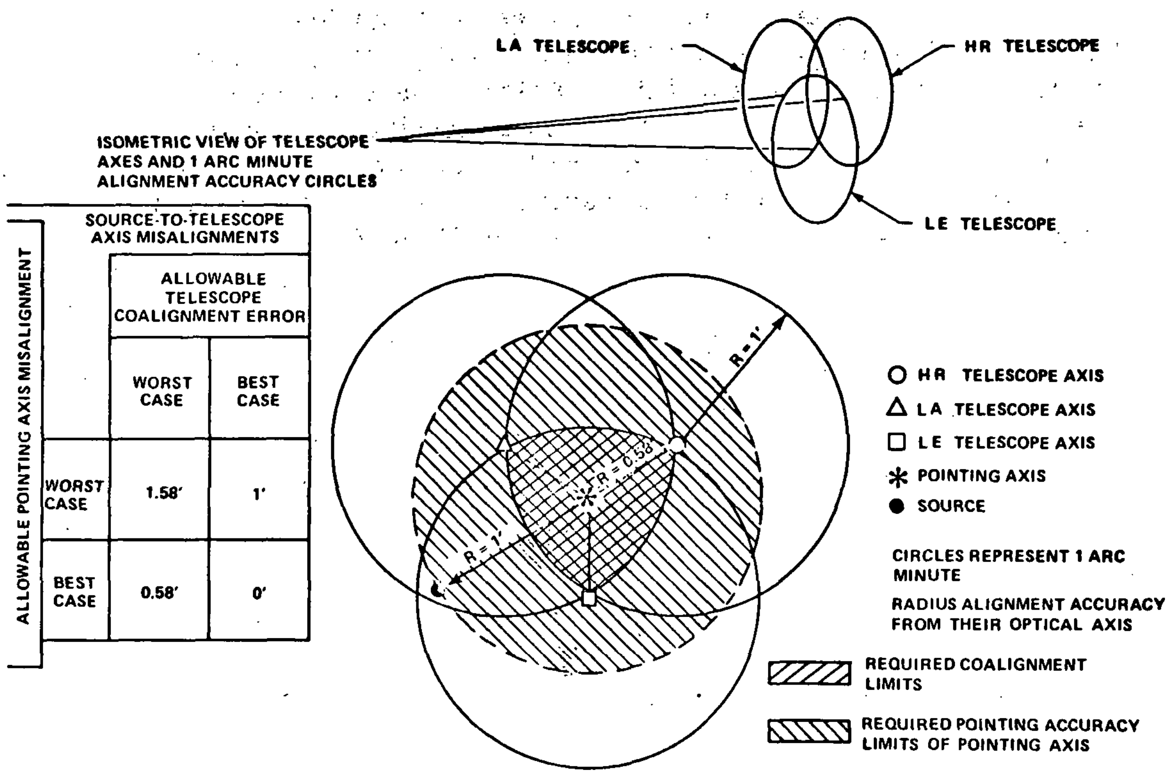


Figure IV-10. Coalignment of three telescope axes and the pointing axis with pointing axis equidistant from telescope axes.

For the axes locations shown in Figure IV-10, the probability that a source that is within 1 arc minute of the pointing axis is also within 1 arc minute of each of the three telescope axes is the ratio of the area common to all three telescopes to the area within 1 arc minute of the pointing axis. This probability is approximately 0.23. The probability that a source that is within 1 arc minute of the pointing axis is also within 1 arc minute of at least two telescope axes is approximately 0.39. The probability that a similarly located source is within 1 arc minute of at least one telescope axis is 1.0 This indicates that, if the pointing axis is held within 1 arc minute of the source (the mission pointing requirement), one telescope will always be within 1 arc minute of the source, two telescopes will be within 1 arc minute of the source about 30 percent of the time, and all three telescopes will be within 1 arc minute of the source about 23 percent of the time. Since the fields of view of all experiments are greater than 1 arc minute, the source will always be visible to all three instruments. The maximum off-axis angle for the configuration shown in Figure IV-10 is about 1.6 arc minutes. If the pointing accuracy of the spacecraft is better than 1 arc minute, the probabilities that two or all three telescope axes will be within 1 arc minute of the source will be increased.

If one of the telescope viewing axes is designated the pointing axis, the probability that the source will be nearer that axis will be increased. This may be desirable when the smallest field of view of the HR telescope imaging experiment (7 arc minutes) is used. It should be possible to move the location of the pointing axis at almost any time during the mission and, as often as desired, by software biasing. Further discussions of instrument alignment and associated error analyses are included in Volumes II and III.

CHAPTER V. SPACECRAFT SUBSYSTEMS

A. Structures

There are four major portions of the structure: (1) the outer structure, consisting of ring frames, eight longerons, stringers, skin, and sunshade; (2) a forward crowfoot beam assembly on which the optical bench is supported; (3) the optical bench, which consists of a dual beam assembly, two ball-and-socket joints, telescope tubes, and aft tube linkages; and (4) miscellaneous mounting hardware. The outer structure serves to isolate the optical bench from direct solar radiation and supports the subsystems (including solar arrays), the sunshade, and the optical bench.

The crowfoot beam assembly takes all the longitudinal launch loads of the optical bench and distributes these loads to several points around the circumference of the outer structure. The optical bench serves as a reference structure for precision alignment of the experiments and the most accurate sensors (rate gyros, star trackers, and digital sun sensors). The mounting scheme was shown in Figures IV-1 and IV-4. The ball-and-socket joints allow relative movement between the optical bench and the other structure, so that thermal or other distortion of the outer structure does not induce stress into the optical bench. The aft linkages on the tubes are required for transverse and torsional launch loads and also limit the movement of the telescope aft ends during on-orbit maneuvers (the link from the LE telescope to the others serves also to maintain experiment coalignment). The alzak skin used for thermal control also serves as a micrometeoroid bumper. Miscellaneous mounting hardware is provided for the experiments and systems.

1. <u>Structural Requirements.</u> General requirements for the structural configuration are listed in Table V-1. A requirement for a minimum lateral natural frequency of 4 Hz was imposed on the spacecraft design to help insure inviolability of the launch vehicle shroud dynamic envelope.

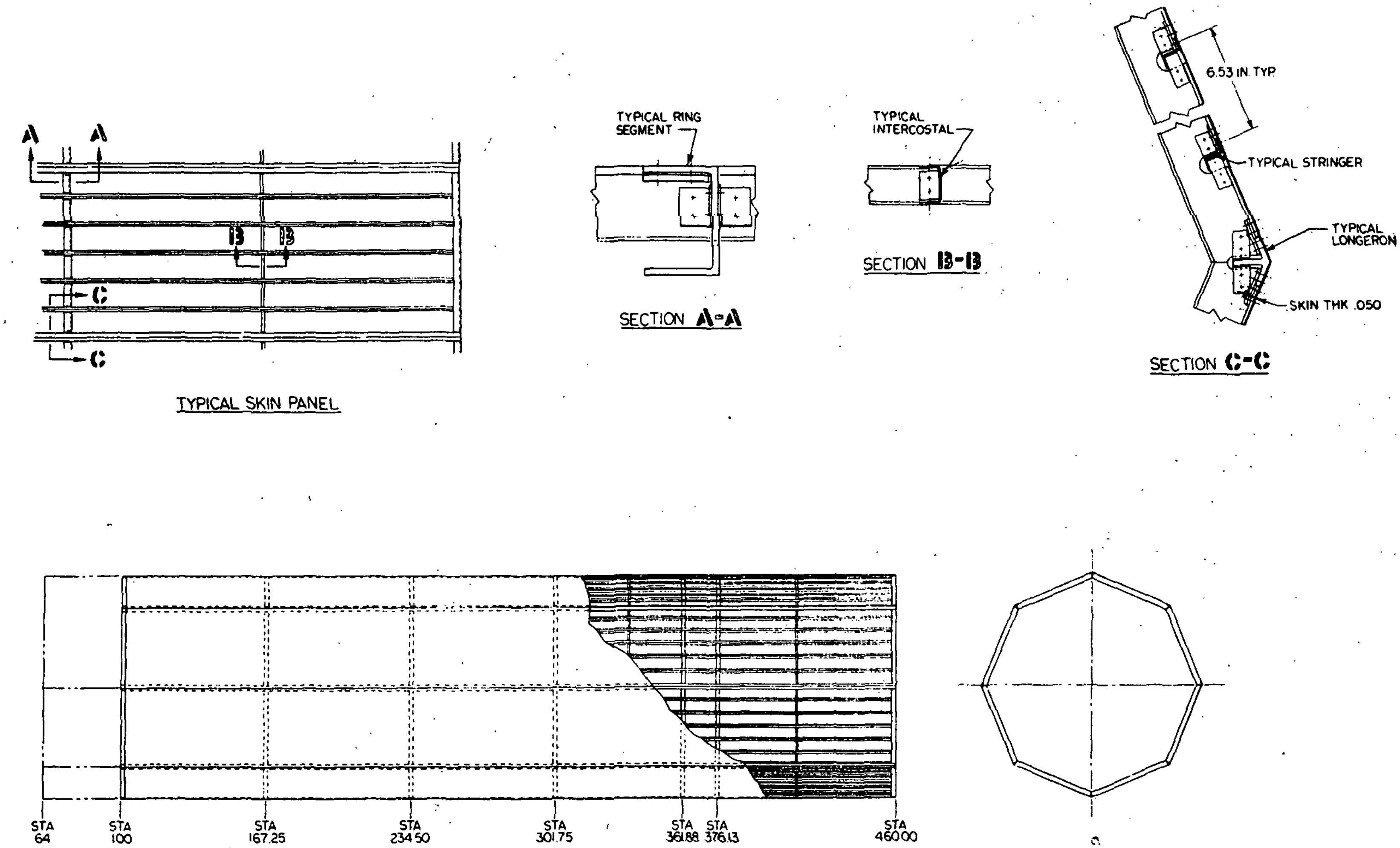
2. <u>Component Analysis</u>

a. Octagonal Spacecraft Structure. All structural elements (Fig. V-1) were sized to fulfill the general requirements. The computed loads in each element are in proportion to the relative stiffness of the element since the thin skin of the structure was not allowed to buckle under the design loads.

TABLE V-1. GENERAL REQUIREMENTS FOR THE STRUCTURAL CONFIGURATION

- Provide a lifetime of two years
- Be capable of being launched with a Titan IIID/OAS kick stage launch vehicle
- Be capable of withstanding the launch loading environment of 6.0 g longitudinal and 1.5 g lateral acceleration, simultaneously, and an ultimate load factor of 1.5
- Maintain a maximum spacecraft dynamic envelope of less than 108.7 in. in diameter
- Maintain parallelism among the telescopes and associated equipment within 1.0 arc min
- Provide isolation of the experiments from the launch-induced vibration
- Provide sufficient structure to limit spacecraft deflections to the following:

High Resolution (HR) Telescope	Large Area (LA) Telescope
Deflection Caused by Thermal Gradients	
±0.002 in. Longitudinal	±0.02 in. Longitudinal
±0.02 in. Lateral	±0.02 in. Lateral
Total Deflection Caused by Loads and Thermal Gradients	
±0.004 in. Longitudinal	±0.04 in. Longitudinal
±0.04 in. Lateral	±0.04 in. Lateral



* LONGERON SIZE (IN)	*RING SEGMENTS SIZE (IN)	* INTERCOSTALS SIZE (IN)	STRINGERS SIZE (IN)
T-2.50 X 1.70 X .25	[-2.50 X 1.75 X .156	[-.87 X 50 X .05	L .87 X .56 X .05

Figure V-1. Details of outer structural design.

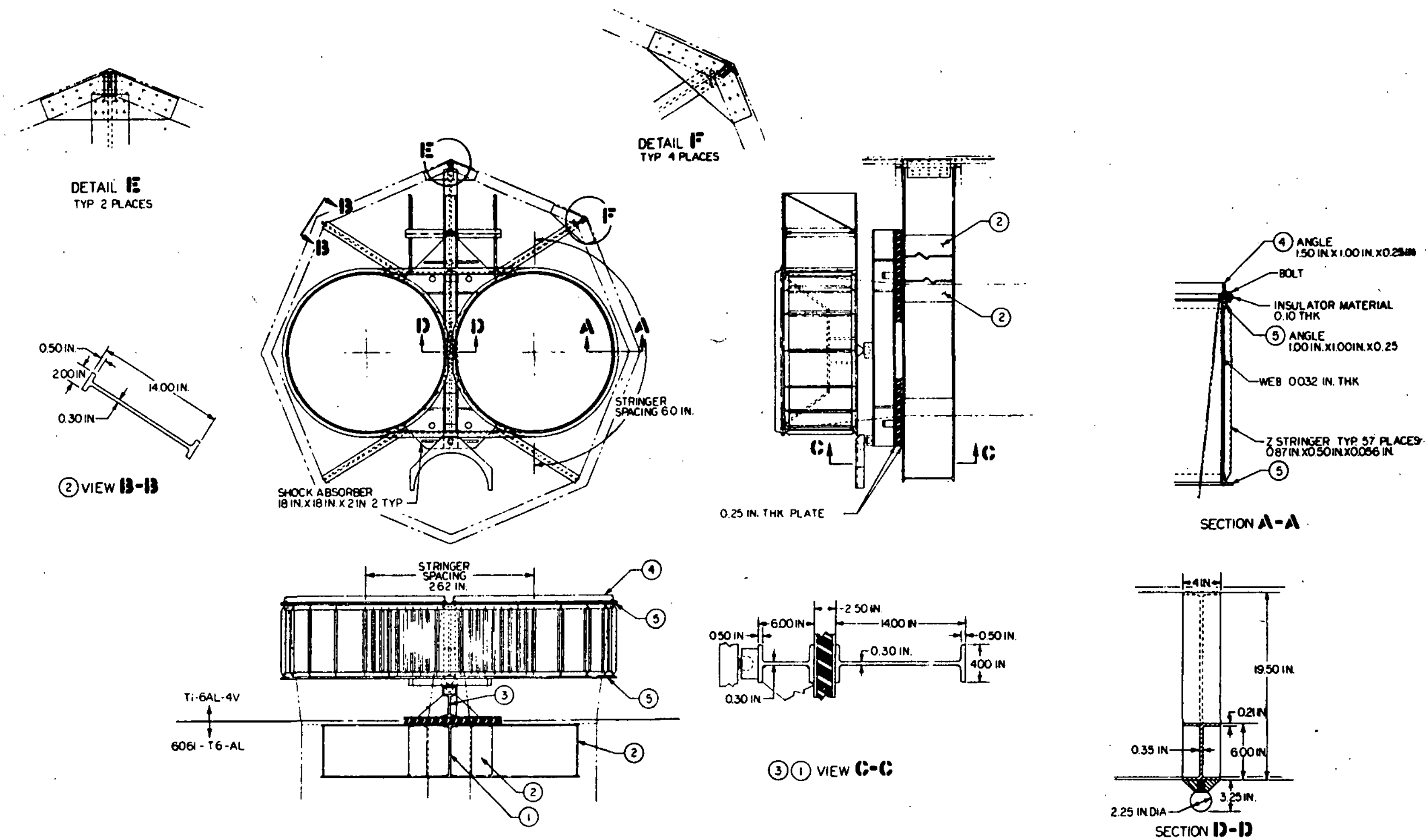


Figure V-1. (Concluded).

In some locations, where the loads are low and the corresponding required skin thickness would be very low, thicknesses were increased to more realistic values. In general, however, the loads determine the panel sizes, skin thickness, and cross-sectional areas shown in Figure V-1.

The spacecraft bending and shear stiffnesses are 32×10^{10} lb-in.^{2} and 52×10^6 lb, respectively. Figure V-2 and V-3 show the contribution the skin, stringer, and longerons make to the overall spacecraft stiffness. The quasi-static defelction, using these stiffness values and conjugate beam methods which include the shear deformation, was estimated to be about 0.7 inch.

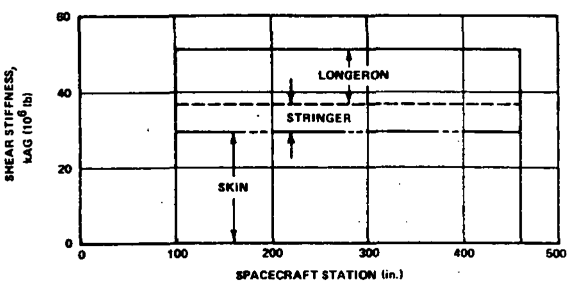


Figure V-2. Shear stiffness as a function of spacecraft station — all axes.

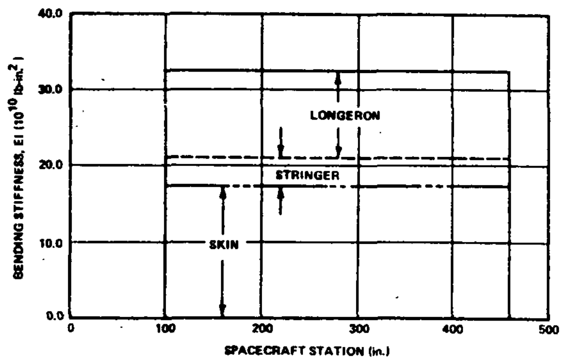


Figure V-3. Bending stiffness as a function of spacecraft station — all axes.

The thicknesses and areas shown in Figure V-1 were used to compute the weights of the various structural components shown in Table V-2.

b. Spacecraft/OAS Adapter. The adapter was sized to withstand the launch loads and provide the necessary stiffness. Detail sizes of the elements are shown in Figure V-4 and were used to compute the weights of the components given in Table V-3.

c. Free Vibration of the Spacecraft Structure. The natural frequencies and their associated mode shapes were computed and are

TABLE V-2. COMPONENT WEIGHT BREAKDOWN

Item	Weight (lb)
Structure[a]	3328
Outer Shell	1370
Frames (7)	197
Stringers	143
Longerons (8)	292
Skin	560
Intercostals (5)	15
Clips (estimated)	20
Adapter Angle (8)	15
Aft End Closure	128
Internal Support	1758
Telescope Support Frame	309
Shock Mount	179
Load Distribution Beam	80
Ball and Socket (2)	35
Oval Ring Frame	252
HR Telescope Tube	167
LA Telescope Tube	293
Bars and Delta Frames, Bearings, Mounts, and Associated Structure (estimated)	443
Mounting Brackets	200

a. Does not include additional 47 pounds for sunshade.

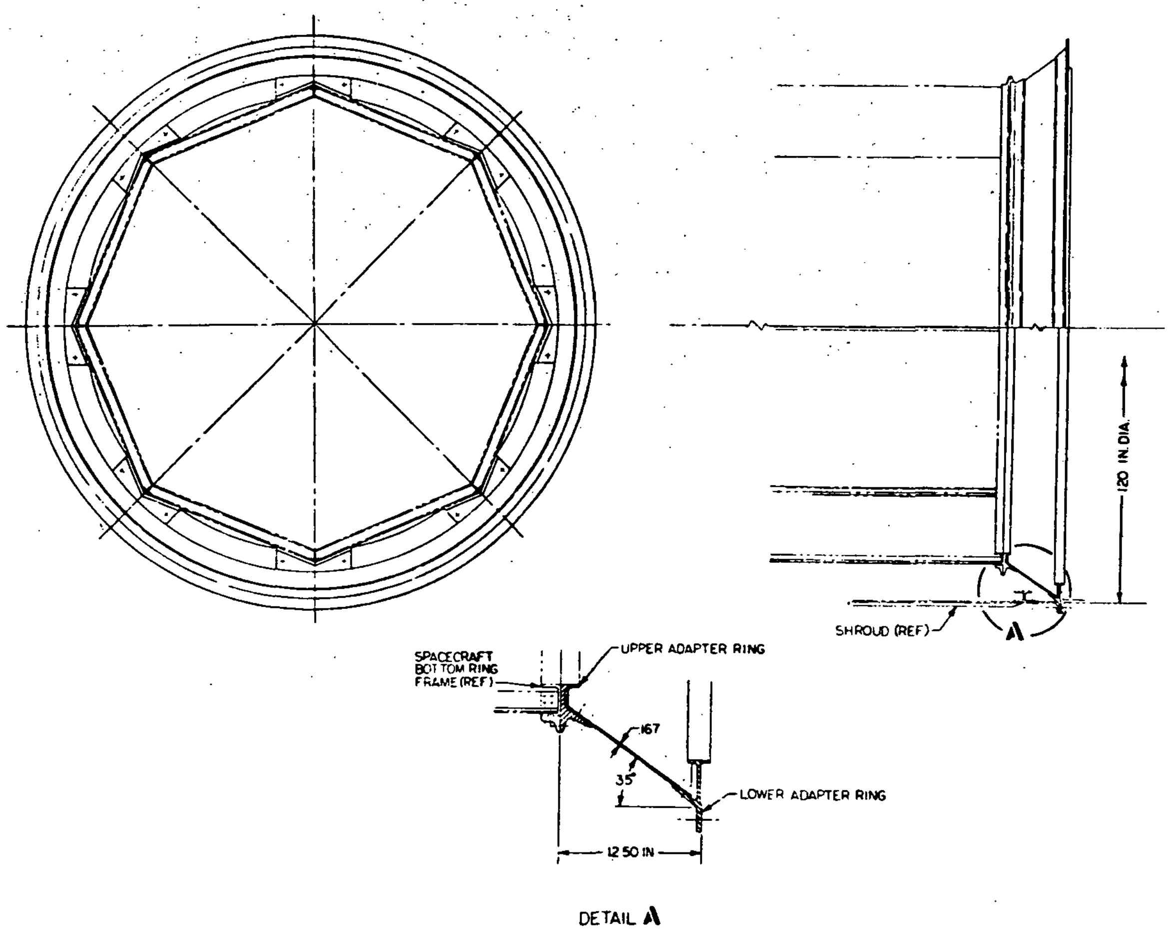


Figure V-4. Details of adapter design.

TABLE V-3. SPACECRAFT/OAS ADAPTER WEIGHT BREAKDOWN

Item	Weight (lb)
Top Ring	50
Bottom Ring	58
Skin, Splices, and Fasteners	104
Total Weight of Adapter	212

depicted in Figure V-5. Assuming a transmissibility of 1.5, the free end dynamic displacement was computed for an input of 1.5 g and is given in Table V-4.

The maximum allowable spacecraft deflection is 1.5 inches, which is much greater than the calculated deflection, so there should be no launch deflection problems.

d. Dynamic Analysis of Shock Mounts. The response of the structure due to the presence of a shock mount was determined for the configuration shown schematically in Figure V-6. A rubber shock mount with a spring rate

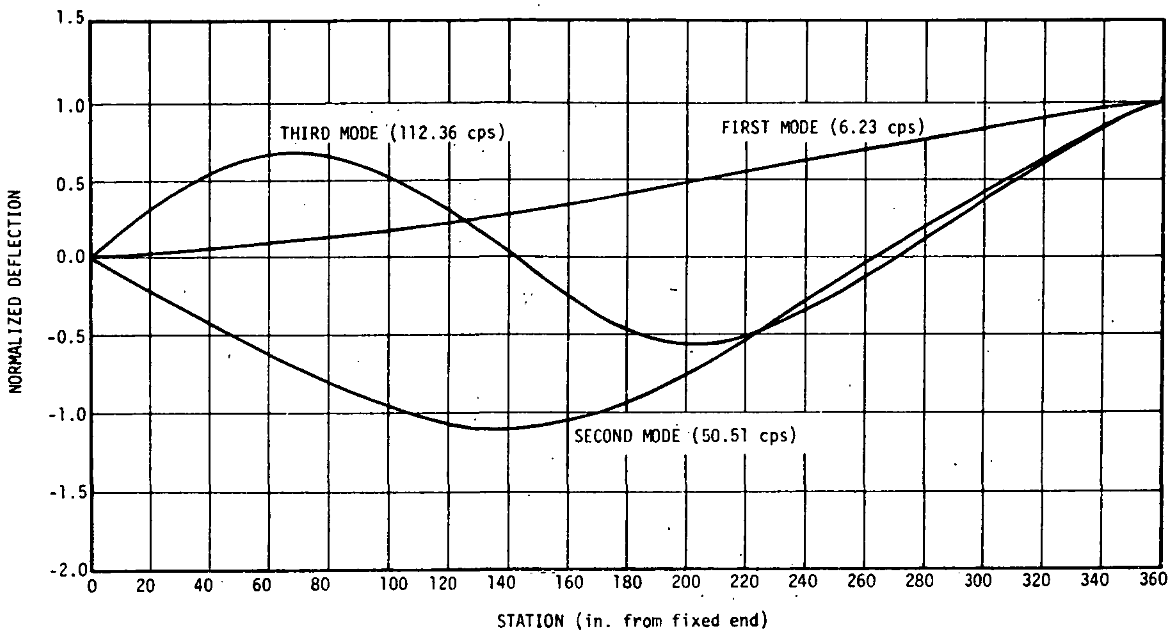


Figure V-5. First three bending mode shapes including shear deformation (normalized with respect to the deflection at station 360).

TABLE V-4. NATURAL FREQUENCIES AND FREE END DYNAMIC DISPLACEMENTS

Mode	Frequency f_n (cps)	Displacement Δ_{out} (in.)
1	6.230	568.320×10^{-3}
2	50.506	8.654×10^{-3}
3	112.355	1.747×10^{-3}
		Total 0.58

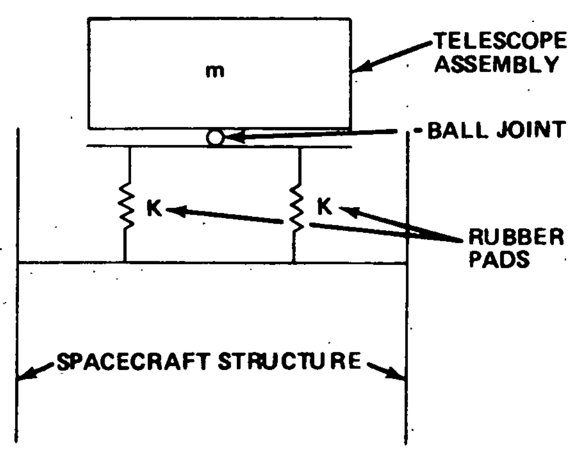


Figure V-6. Baseline design with shock mounts and ball joint.

of 256 lb/in.^{2}/in. and dynamic shear modules of 0.12 gives the system a natural frequency of about 14 Hz. If the system were excited at this frequency, the transmissibility would be 8.6 as shown in Figure V-7 and high loadings could result depending, of course, on the input force. Exciting forces in the 14 Hz range should be avoided and further dynamic investigation should be made in the later design phases.

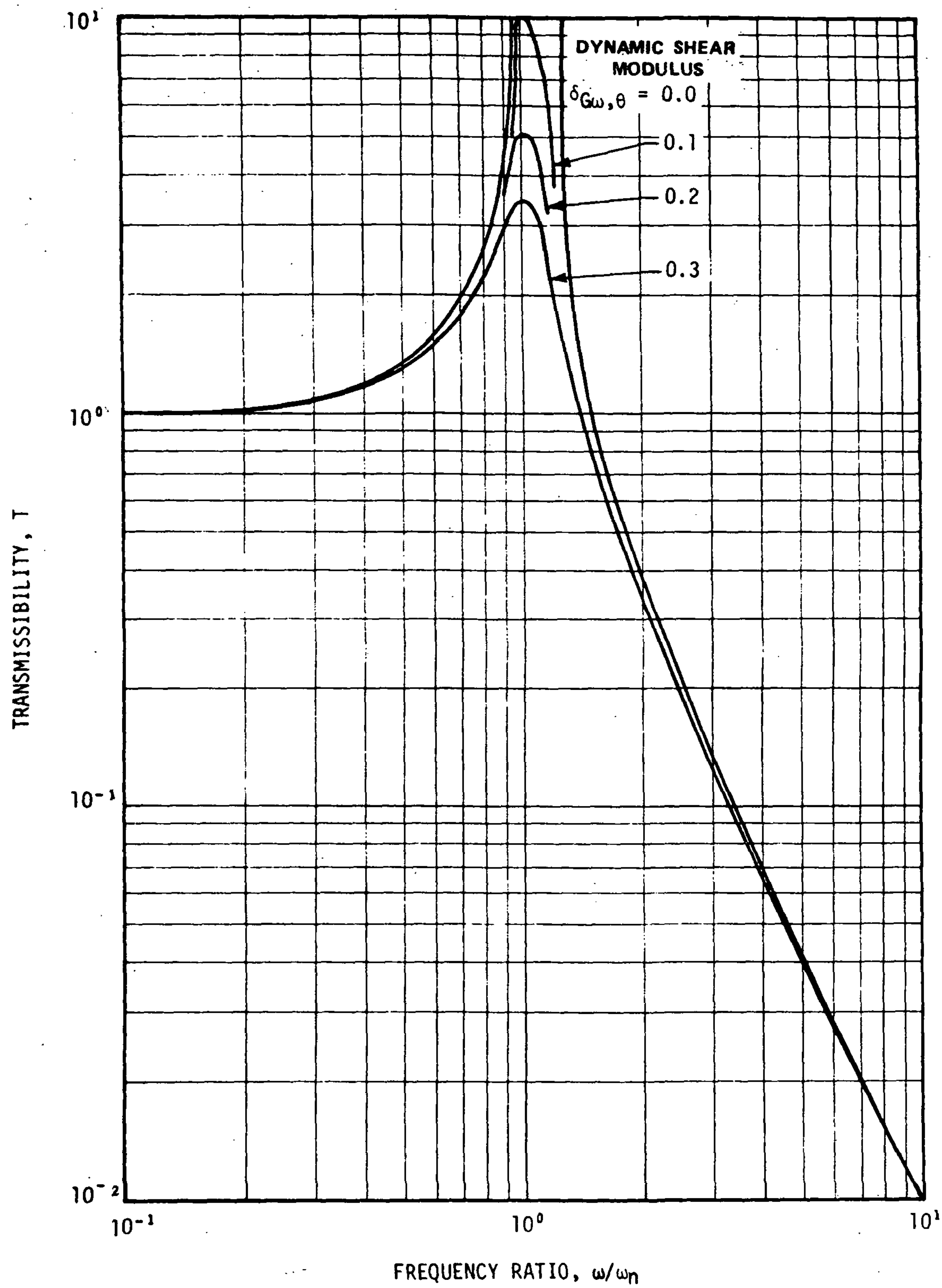


Figure V-7. Transmissibility as a function of frequency.

e. Thermal Bending Analysis. Thermal bending of the spacecraft due to a temperature variation in the circumferential direction was determined by the simultaneous solution of three partial differential equations. The analysis showed that from a thermal viewpoint alone, decoupling of the optical bench from the outer structure (i.e., the ball joint, shock mount design) would probably not be required. (The computed maximum temperature across the spacecraft with the baseline thermal control system is less than 5°F.) However, the design was retained for conservatism and alignment consideration.

f. Solar Cell Substrate. The solar cell substrate is designed to limit the deflection between supports to prevent cell pealing. The 0.700 inch thick, honeycomb panel deflects 0.013 inch at about 1000 psi stress level. The panel's first natural frequency is 38 Hz which lessens the possibility of vibration problems during launch.

g. Meteoroid Protection Analysis. The spacecraft meteoroid protection requirement was determined by a method that relates the ballistic limit of the protection material to the exposed spacecraft surface area, exposure time and desired probability of no penetration. A dual wall shield utilizing the spacecraft outer skin as one wall is employed. The thickness of material required to protect an object some distance inside the spacecraft is determined by Figure V-8. This thickness requirement is considered conservative since it is based on the total spacecraft surface area and is not on the area of the particular components or objects to be protected.

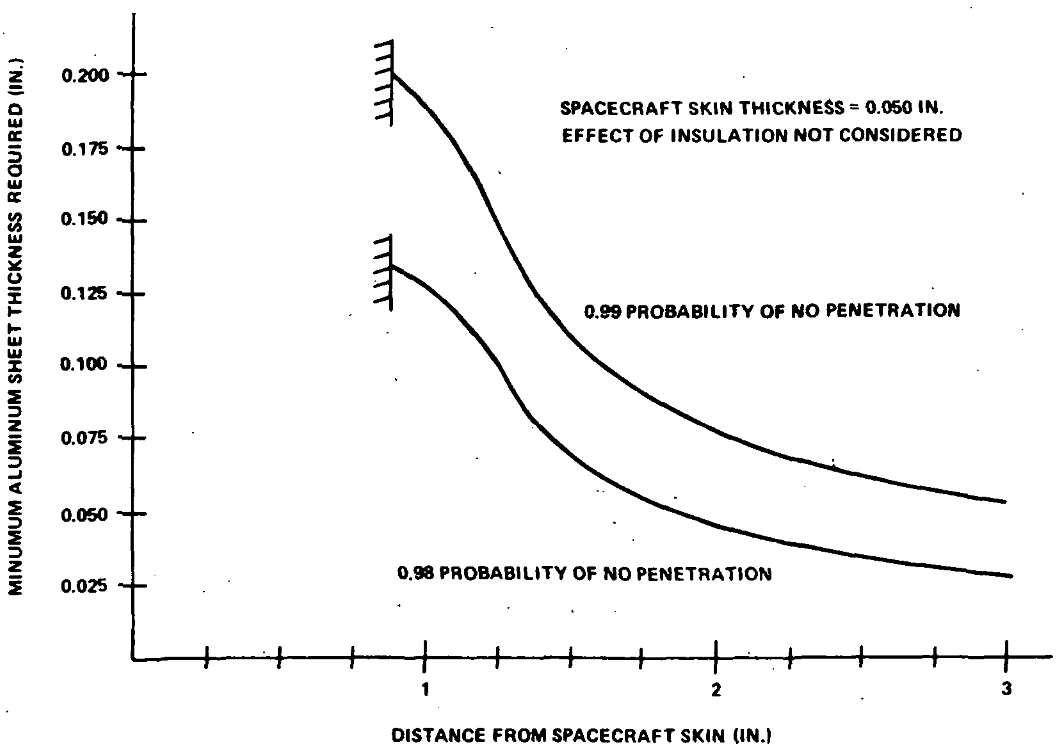


Figure V-8. Component meteoroid protection thickness requirements.

4. Commonality. Structural component commonality with the HEAO-A and -B configuration does not exist per se for the Phase A concept; however, in the design and analysis, every effort was made to utilize the applicable philosophies established by HEAO-A and -B. As the spacecraft designs mature, a reasonable degree of commonality should be achievable.

Currently, some of the outer structure members (stringers, ring frames, and longerons) from HEAO-A and -B might be useable on HEAO-C, but this usage may not be great because of the differences in experiments and their attach points and load paths. One key difference in outer structure design is that HEAO-C must utilize structural skin for shear strength; whereas, HEAO-A and -B obtain shear strength through transverse shear webs and bulkheads.

The detail HEAO-C design can be made to utilize many of the HEAO-A and -B facilities (that is assembly facilities and fixtures, handling fixtures, etc.). The use of these facilities and tools should certainly result in cost savings.

B. Thermal Control System

Thermal control of the Observatory experiments and subsystem components is accomplished by using multilayer superinsulation on the telescope tubes and mirror assemblies and on most of the external structure, thermostatically controlled heaters on the mirror assemblies, a thermal control filter covering the Observatory aperture end, graphite/epoxy as the telescope tube material, a thermally independent subsystems compartment, alzak external skin, thermal control coatings, and a sunshade (Figs. V-9 and V-10). The system eliminates virtually all transient orbital effects (mandatory for precise optical alignment), protects the telescopes and other experiments and sensors from solar radiation for all orbit and Observatory design orientations (Fig. V-11), reduces axial and transverse temperature gradients to well below acceptable values, and permits the subsystem components to be adequately thermally controlled virtually independent of the experiments. Major design features are summarized in Table V-5.

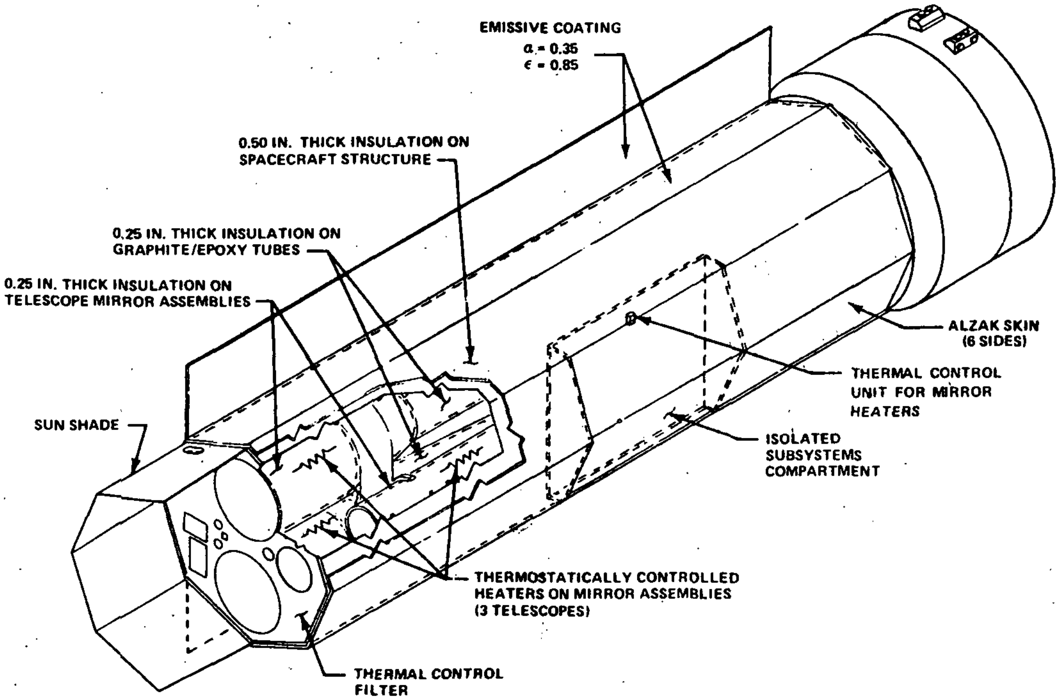


Figure V-9. HEAO-C thermal control system elements.

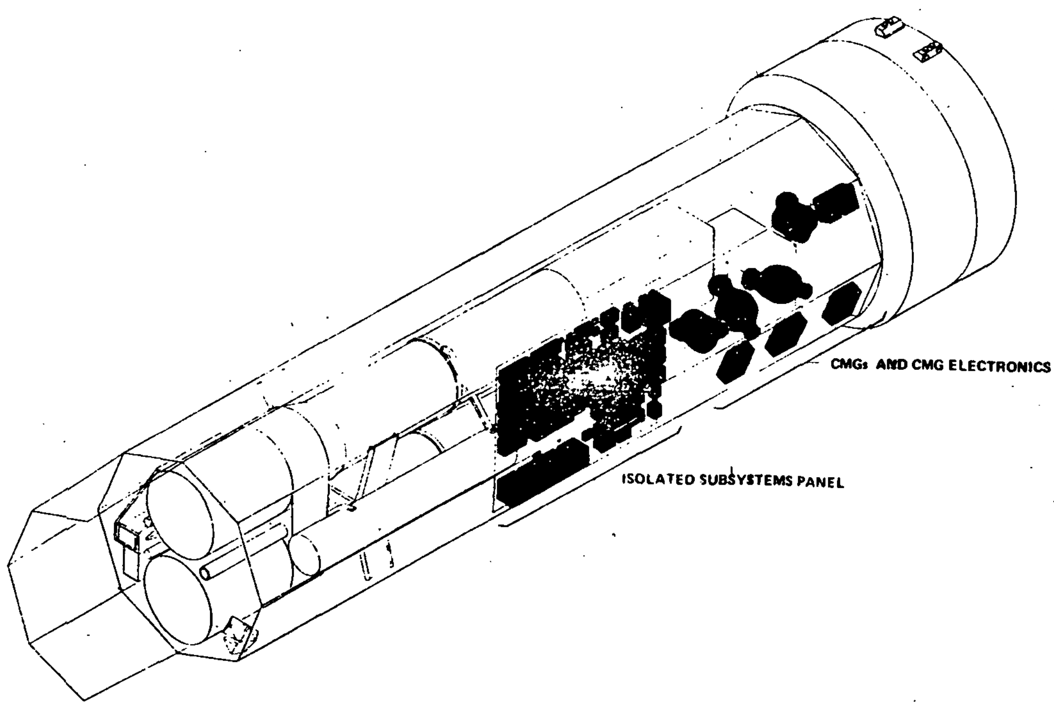
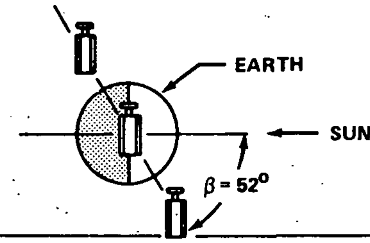
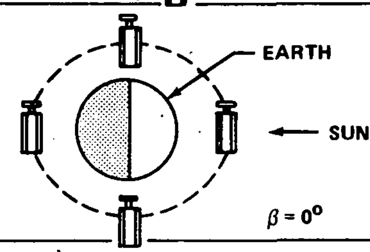


Figure V-10. Subsystems locations.

CASE I – "HOT" ORBIT
MAXIMUM TIME IN SUNLIGHT,
MAXIMUM ORBITAL AVERAGE HEAT LOAD



CASE II – "COLD" ORBIT
MINIMUM TIME IN SUNLIGHT,
MAXIMUM INSTANTANEOUS HEAT LOAD



CASE III – 30 - DEGREE TILT
VIEWING END INCLINED 30 DEGREES TOWARD THE SUN TEMPORARILY (~1 ORBIT/DAY);
WORST CASE TEMPORARY HEAT REJECTION REQUIREMENT FOR OPTICAL BENCH

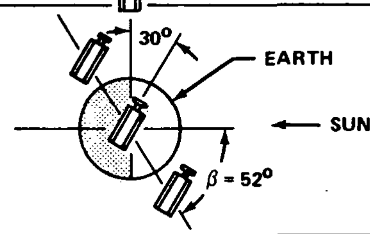


Figure V-11. Observatory and orbit orientations considered in the thermal analysis.

TABLE V-5. MAJOR DESIGN FEATURES

- Experiment temperatures are almost totally insensitive to changes in orbit and/or Observatory orientation.
- The inter- and intra-telescope thermal deflection and alignment requirements are satisfied with significant margin.
- The external insulation scheme, ball joint telescope support, and graphite/epoxy tube material supports a highly conservative and flexible thermal control system.
- The system is semipassive and all hardware (except for graphite/epoxy) is essentially off-the-shelf.

1. Component Description

a. Multilayer Insulation (MLI). Multilayer insulation is applied externally to the Observatory to retard the orbital transient thermal effects on the structure. In addition, the telescope tubes and mirror assemblies are lightly insulated yielding a highly thermally stable telescope complement. The MLI technology has advanced rapidly in recent years and any one of a number of existing systems could be used. For the purposes of this Phase A study a double aluminized mylar MLI system was assumed with approximately 30 layers covering the outer structure and 15 layers on the telescope tubes and mirror assemblies with a conductivity of 2.5×10^{-5} Btu/hr ft°F. Venting of the MLI is accomplished by means of perforations in each mylar sheet.

b. Thermal Control External Surfaces. Most of the Observatory external surface is composed of a thin aluminum sheet (alzak, 0.020 in.). This emissive surface provides some meteoroid protection, protects the fragile external insulation during transportation and handling and serves as a base for special coatings which must be applied to the Observatory surfaces adjacent to the foldout solar arrays and to the exterior surface of the subsystems compartment. The thermal analyses conducted were based on the use of S-13G paint at those locations.

c. Electric Heaters. As the Observatory design evolved through the Phase A study it became apparent that to maintain the telescope mirror assemblies within the specified temperature level and gradient limits, electric heaters would be required. Time limitations did not permit the inclusion of heaters in the Observatory thermal model; however, a heater system configuration was developed and sized for the high resolution (HR) telescope mirror assembly, the most temperature-sensitive item.

Strip, mesh-type, and spray-on electric heaters were considered. The mesh-type heaters were chosen because they are highly reliable and easily applied. It was determined that the HR telescope mirror assembly can be thermally controlled with six 2 inch mesh-type heater bands applied circumferentially and spaced axially on the outboard surface of each of the cylindrical mirror sections. An average of 10.3 watts is supplied to the total system and each of the six heaters is individually thermostatically controlled.

2. Requirements versus Capabilities (see Tables V-6 and V-7). The most stringent thermal control requirements are those imposed by the HR telescope. It is required that the position of the detector(s) associated with the HR telescope be maintained to within ±0.002 inch axially and ±0.02 inch transversely of the alignment position. (These are one-half of the total allowable deflections, the remainder allocated for structural alignment tolerances.) The thermal alignment requirements of the large area (LA) telescope are less

TABLE V-6. THERMAL CONTROL SYSTEM COMPONENTS

Component	Weight (lb)
Multilayer Insulation (Double Aluminized Mylar)	90
Paints (S-13G)	70
Heaters (Mesh-Type Strips) (10.3 watts avg. power)	15
External Skin (Alzak)	300
Total Thermal Control System Weight	505

TABLE V-7. REQUIREMENTS VERSUS CAPABILITY

Requirement	Capability
High Resolution Telescope	
Mirror Gradient Limits	
±5°F Transversely ±2.5°F Axially	Transverse Gradient — Negligible ±7°F Axially, With No Heater Power. Reduced With Heaters
Mirror/Detector Alignment	
±0.002 in. Axially ±0.02 in. Transversely	Axial Displacement — Negligible Transverse Displacement — Negligible
Large Area Telescope	
Mirror Gradient Limits	
Same as HR Telescope	Transverse Gradient — Negligible Axial Gradient — Not Determined; Probably Will Need Heaters
Mirror/Detector Alignment	
±0.02 in. Axially and Transversely	Axial and Transverse Displacements — Negligible
Low Energy Telescope	
Allowable Temperatures	Satisfied, Except Detector is 76°F — Can Be Reduced By Altering Insulation
50°F to 68°F	
Subsystems	
Batteries Are Driver; Need 40 to 60°F	Satisfied (Will Probably Require Louvers/Heaters to Assure Control on Critical Components)
Solar Arrays	
Limit Temperature to 212°F	Maximum Temperature is Less Than 200°F

stringent and did not drive the design. The HR telescope alignment requirements and the requirement for coalignment of the three telescopes to within ±1 arc minute paced the thermal (and structural) design. The decision to insulate the Observatory externally and the choice of the thermally stable graphite/epoxy composite as the telescope tube material was motivated by these alignment criteria. The analysis has shown that all of the requirements are met with significant margin. The expected axial temperature gradient of HR telescope tube is on the order of a few degrees. Consequently, the only contribution to axial defocusing comes from mirror assembly gradients which are retarded adequately by the electrical heater system. The transverse temperature gradient was analytically determined to be less than 5°F.

The low energy (LE) telescope is required to be maintained within the 50°F to 68°F temperature band. This requirement is satisfied except for slightly higher temperatures (approximately 8°F) at the detector end of the telescope. It is difficult at this time to judge the significance of this discrepancy (due to an understandable lack of telescope design detail); however, it seems easy to attain temperatures consistent with the requirement by slightly altering the telescope and/or Observatory insulation scheme.

All subsystem electronics except those few which are location-sensitive are thermally controlled by exploiting the available volume and the thermally stable external surface on the antisolar side of the Observatory. Most of the components are contained within an independent subsystems compartment, thermally coupled only to the outer skin. The CMGs and related electronics are thermally coupled to both outer skin and experiment detectors. The subsystem electrical components located on the antisolar side of the Observatory are controlled by altering the properties of the adjacent external surface. This alteration can be made during the thermal vacuum test phase of development. The surface area is sufficiently large that the required properties are well within the limits attainable by state-of-the-art coatings. From Figure V-12 it can be seen that a subsystems compartment external surface emissivity of 0.62 will allow the components to operate at an orbital average temperature of 50°F (assuming that all components are operating simultaneously).

The upper limit on solar array temperature was specified for this study at 212°F. For all orbit and Observatory design orientations the maximum array temperature is maintained well below 200°F. As illustrated by Figure V-13, the body-mounted solar cell packing density could be increased to approximately 60 percent (the packing density on the baseline design has an average value of 0.42) before encountering the temperature limit.

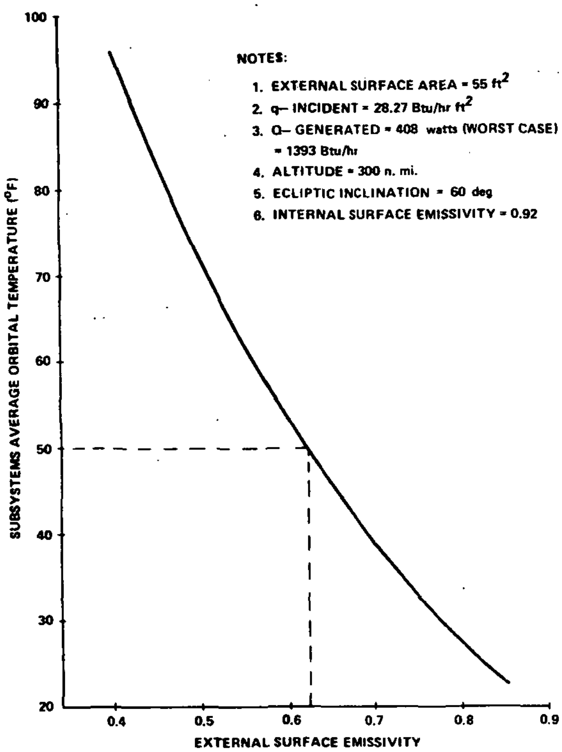


Figure V-12. Subsystems compartment average orbital temperature versus external surface emissivity.

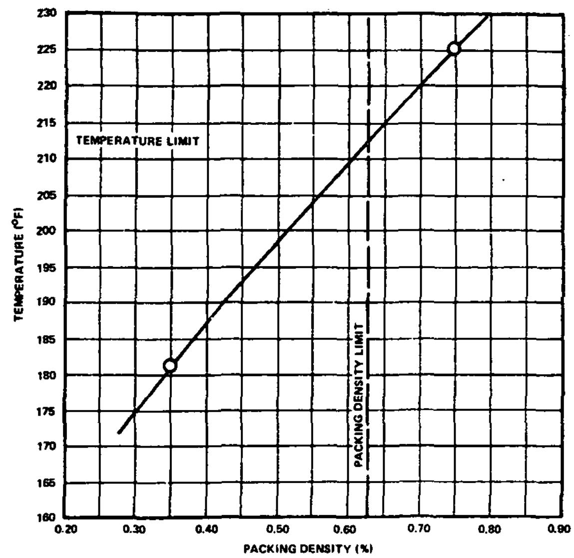


Figure V-13. Temperature versus packing density for body-mounted solar arrays.

The thermal control concept can be made to satisfy all of the imposed requirements. Except for thermostatically controlled heaters, the system is passive. The ball joint telescope support scheme and the use of graphite/epoxy in the telescope tubes supports a stable and highly conservative thermal control system. There is a significant margin for growth.

3. Trade Studies. The telescope tubes are an integral part of both the HEAO-C structural and thermal control systems. An analysis was conducted early in the study to determine which of a number of candidate materials was most attractive for use as the tube material. Beryllium, titanium, invar, aluminum, boron-epoxy, and graphite-epoxy were compared, considering weight (density and stiffness), thermal conductivity, thermal expansion, and cost (material cost and ease of fabrication). Although results are significantly dependent on the methods and assumptions used in the analysis, current rapid advancement in the state-of-the-art of composite materials supported the choice of graphite/epoxy.

4. <u>Commonality.</u> The HEAO-C thermal control approach is very nearly the same as that proposed for the HEAO-A/B spacecraft. Since all of the thermal control hardware (except graphite/epoxy) is essentially off-the-shelf, the total cost is low. Also, HEAO-A/B type insulation and heaters can be adapted for use on HEAO-C.

C. Attitude Sensing and Control System

The attitude sensing and control system (ASCS) senses and control the motion of the HEAO-C spacecraft during all maneuvering and pointing phases of normal operation as well as sun acquisition, reacquisition, and orbit adjust burns. The celestial pointing mode permits aiming the experiments to any location on the celestial sphere to a two-axis accuracy of one arc minute, and a special pointing mode provides the capability for pointing experiments at infrequently occurring "flare" sources. For sensors, the system uses reference gyros, sun sensors, and star trackers (in addition, magnetometers were considered for an alternate system). The actuators are control moment gyros (CMGs) and a hydrazine reaction control system (RCS). (An attractive alternate also includes magnetic torquers and an RCS modification to a cold gas system as delineated in Appendix E, Volume III.) The required electronics are provided either integrally or separately for each sensor and actuator system. Digital computers provide the necessary signal processing and software calculations, and a transfer assembly serves as the interface between all ASCS sensors, actuators, and computers. Figure V-14 shows the location of the ASCS components, Figure V-15 is a block diagram of the baseline configuration, and Tables V-8 and V-9 give the ASCS hardware summary.

1. <u>Component Description</u>

a. Sensors. Each wide angle sun sensor (WASS) is a Bendix unit with separate electronics that can provide continuous two-axis sensing with respect to the sunline over a 20 degree solid cone with saturated polarity information out to 2π steradians. This selection was made based on commonality with HEAO-A/B, availability, and low cost. Two are located on the solar panel side (+Z-axis) with one aligned with the -Z-axis (Fig. V-14) to give 4π steradian coverage and adequate redundancy. Two digital sun sensors (DSSs) and electronic assemblies, one active and one standby to provide acceptable reliability, are aligned with the +Z-axis. Each can provide accurate two-axis information for +Z-axis deviations from the solar vector up to a maximum offset of 32 degrees. The Adcole design was selected based on

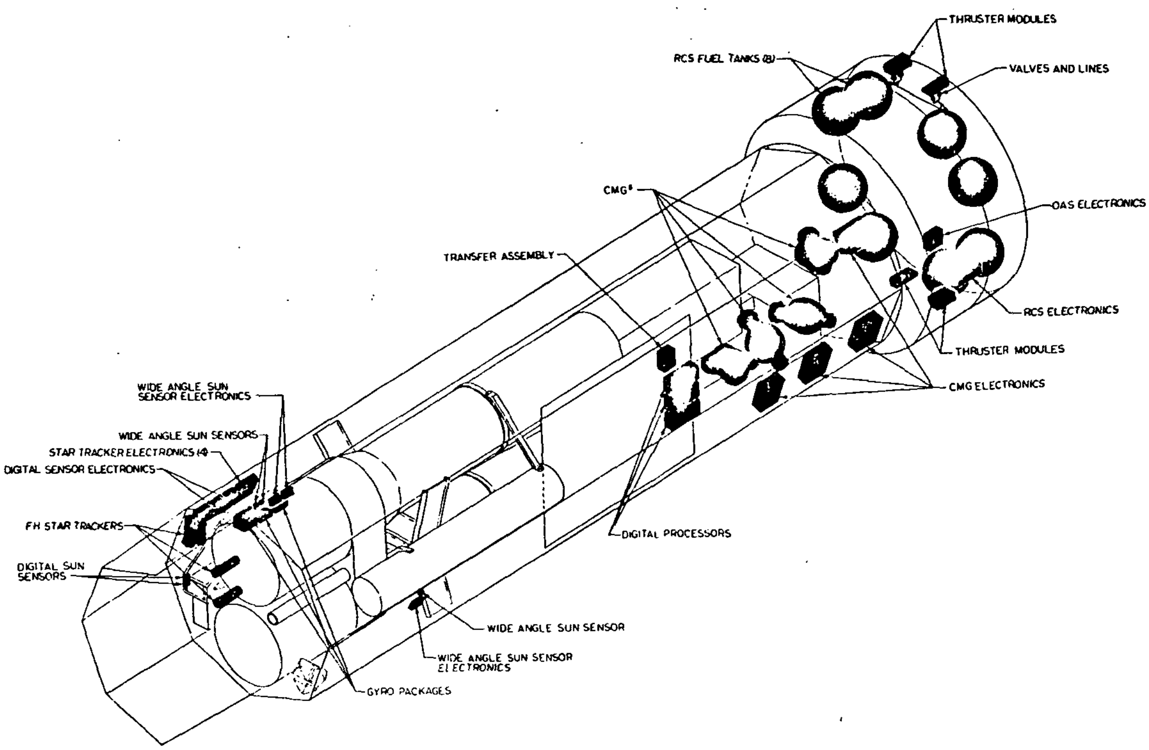


Figure V-14. Location of the ASCS components.

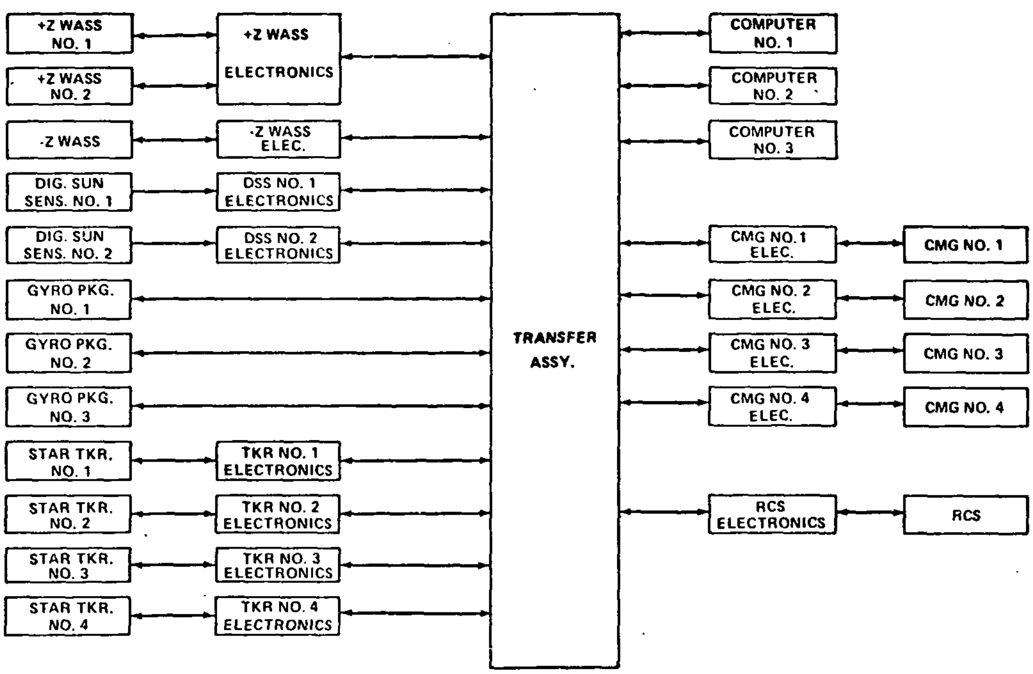


Figure V-15. HEAO-C ASCS baseline configuration.

TABLE V-8. HEAO-C ATTITUDE SENSING AND CONTROL

Item	Number of Units	Unit Weight (lb)	Unit Size (in.)	Avg Unit Power (W)	Type
Wide Angle Sun Sensors	3	1	2 × 1.9	0	Bendix 1818787
WASS Electronics	3	1	5 × 7 × 2	0.4	Bendix
Digital Sun Sensors (DSS)	2	0.75	3.8 × 3.8 × 1.5	0	Adcole
DSS Electronics	2	2.5	7.8 × 5 × 2.5	1.7	Adcole
Gyro Package	3 (2-Gyro)	11	7 × 8 × 6	15	TRW (Nortronics)
FHSTs	4	9	15 long × 4 dia	0	ITT
Star Tracker Electronics	4	14	5 × 11 × 12	8 (Estimate)	ITT
CMG (250 ft-lb-sec)	4	135	32 × 19 × 19	9 (32 spinup)	Bendix
CMG Electronics	4	27	12 × 16 × 7	18	Bendix
Processor and Computer	3	20	18.5 × 5 × 8	65	Bendix
Transfer Assembly	1	10	5 × 7 × 10	5	Bendix
RCS Electronics	1	16	9 × 14 × 7	11	Bendix
Total System Weight		871.5			
Average System Power				252.1	

TABLE V-9. HEAO-C REACTION CONTROL SYSTEM DATA SUMMARY

Item	Number of Units	Unit Weight (lb)	Unit Size (in.)	Avg. Unit Power (watts)	Type
GN_2 Fill and Drain Valve	8	0.25			LMSC
Propellant Fill and Drain Valve	2	0.30			LMSC
Isolation/Shutoff Valve	19	0.60		0.1 (failure mode only)	LMSC
Tank, Including Thermostats and Heaters	8	17.25	22.25 in. dia. sphere	1.65	LMSC
Pressure Transducer, Other than REM	24	0.30			LMSC
Temperature Transducer, Other than REM	8	0.14			LMSC
Filter	2	0.25			LMSC
REM, Including Thermostats and Heaters, Instrumentation, and Other Associated Equipment	4	9.00	6 × 7 × 11	6.15	LMSC
Plumbing		10.00	N/A		LMSC
RCS System Dry Weight	1	206.82			
Propellant N_2H_4		829.00			
Pressurant GN_2		19.00			
Total RCS Weight	1	1054.82			

HEAO commonality and availability. The reference gyro assembly consists of six hydrodynamic gas bearing spin axis gyros contained in three reference gyro packages. Each package consists of two gyros and electronics, arranged with parallel input axes with only one set operative, thereby providing sufficient redundancy and reliability. The input axes of the three packages are aligned to the three orthogonal control axes. The Nortronics GI-K7G gas bearing gyro was selected to meet the mission lifetime and low drift requirements. Four fixed head star trackers (FHSTs) and separate electronics, each with a 6 degree diameter field-of-view (FOV) and 6th magnitude star sensitivity are oriented as illustrated by Figure V-16 to provide acceptable performance, redundancy, and reliability. Although not common with any of the HEAO Phase B study efforts, an ITT FHST design concept was selected based on a tracker selection and digital computer star search analysis. This analysis also revealed that for any celestial pointing direction and with only one active tracker per axis, a star fix (one star in each of the X- and Y-axis trackers) can be obtained 91 percent of the time.

b. Actuators. Four Bendix MA500 CMGs, each with separate electronics and minimum modification (such as removal of gear trains, provision of slip rings for unlimited gimbal freedom, and reduction of wheel speed to 4000 rpm to give 250 ft-lb-sec per CMG), are arranged as illustrated in Figure V-17. A β angle of 53.1 degrees was selected to provide nearly equal momentum capability for each control axis. The CMG selection utilized HEAO Phase B study results and provides commonality between HEAO Missions A, B, and C. Since it is a costly item, the same CMG developed for Missions A and B should result in a developed and qualified item for HEAO-C at minimal cost. In addition, many analyses and computer simulation runs have been performed to substantiate this selection for HEAO-C. Based on simulations to date, required performance can be met using three CMGs, and when using the magnetic coils of the alternate control system concept, two out of four CMGs can fail, thereby further enhancing redundancy and corresponding reliability.

Commonality with HEAO-A and -B was the primary driver in determining the type of RCS for HEAO-C. The HEAO-C RCS total impulse requirement, approximately 115 000 lb-sec, is essentially of the same magnitude as for Missions A and B; therefore, a monopropellant hydrazine RCS similar to that established in the Phase B studies was chosen.

The HEAO-C RCS is located in the OAS as shown in Figure V-14. Thus, the reaction engine modules (REMs) are located as far from the telescope viewing end as possible, thereby reducing the chance of contamination.

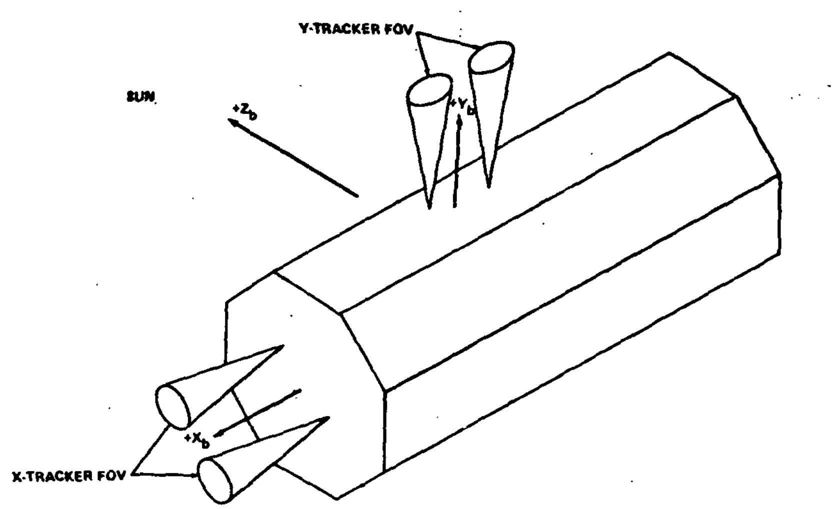


Figure V-16. HEAO-C star tracker configuration.

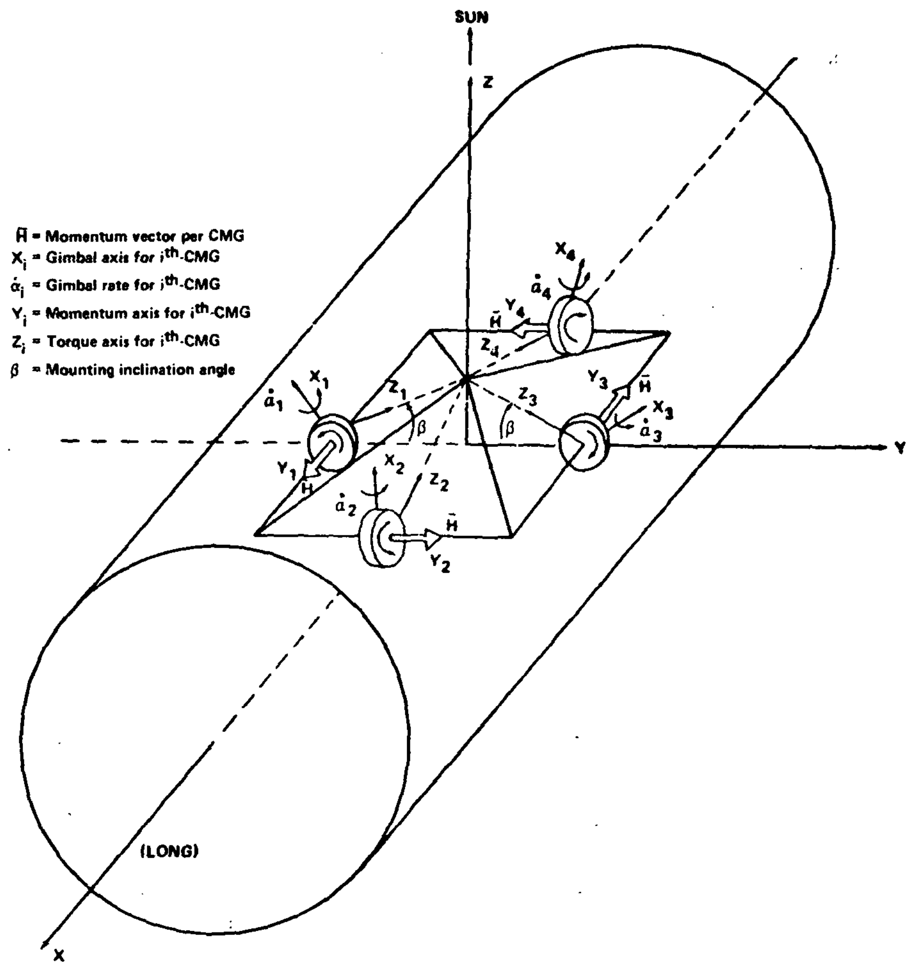


Figure V-17. Four-CMG skewed configuration.

The RCS is basically a modified version of the Lockheed satellite control section (SCS) RCS. Modification is necessary to meet the HEAO-C two-year lifetime and to provide maximum reliability.

A functional schematic of the baseline RCS for the HEAO-C is shown in Figure V-18. The RCS is a blowdown, pressure-fed, hydrazine, monopropellant, propulsion system consisting of propellant tanks, REMs, reaction engine assemblies (REAs), and latching solenoid isolation valves as main elements. The RCS weights are included in the data summary presented in Table V-9.

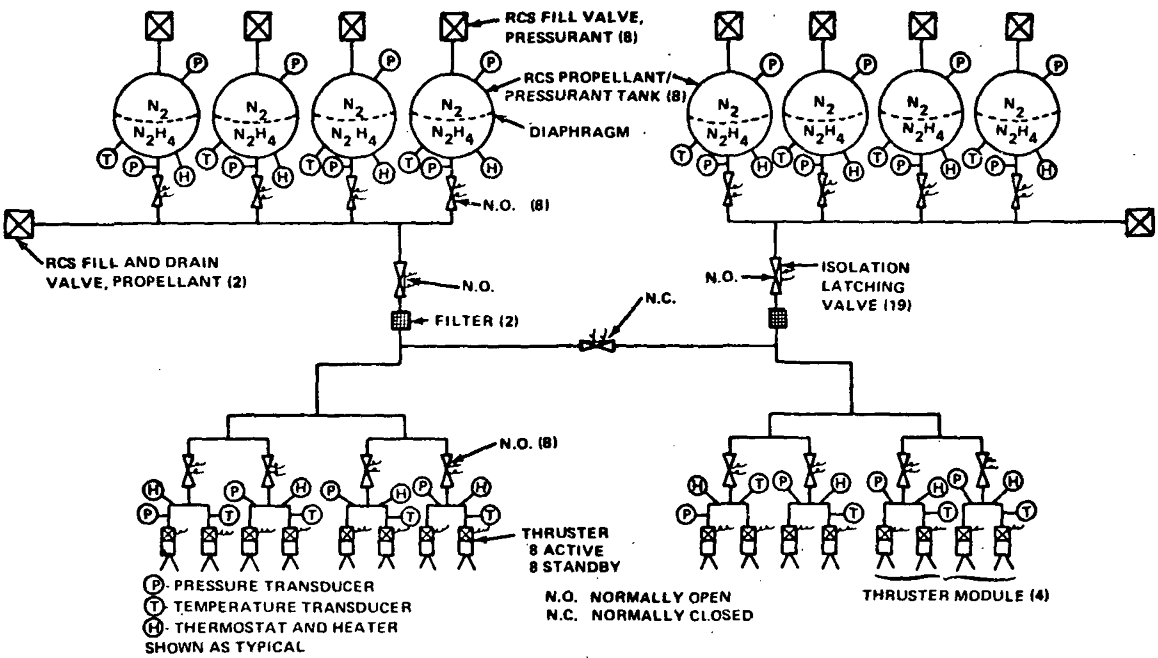


Figure V-18. System schematic of the baseline HEAO-C RCS.

The need for 822 pounds of N_2H_4 for the 2 year HEAO-C mission and the associated number of tanks required to contain this propellant is based on an assumed REA average specific impulse of 140 seconds. This value is believed conservative, and if a specific impulse as high as 200 seconds can be achieved, 250 pounds of redundant N_2H_4 will result.

Each REM consists of four REAs delivering nominally five pounds thrust each to provide spacecraft roll, yaw, and pitch attitude control. Four REMs are used in connection with the HEAO-C RCS, representing a total of 16 engines. Two REAs in each REM are active and two are standby.

c. Signal Processing. The digital processor and computer selected for the HEAO-C is the Bendix BDX-900 unit as baselined during the Phase B study effort. Three are required to satisfy the reliability goal. The capability of this computer is typical of many available on the market and as the HEAO-A/B computer is developed and becomes better defined, it should also become the primary choice for HEAO-C. Although the basic software functions for the HEAO-C are functionally described, a detailed software specification cannot be given until the actual computer selection is made based on the desire for commonality between systems for all missions.

2. Requirements versus Capabilities (Table V-10). By design, the baseline ASCS for the HEAO-C has a pointing capability that exceeds the basic specifications so that additional system errors (such as thermal warpage and alignment errors) do not cause the overall specification to be exceeded. The most critical ASCS accuracy items are the FHSTs and the CMGs. For growth potential, there seems to be little advantage in considering the selection of more accurate reference gyros since the random drift rate of 0.015 deg/hr, 3σ, is pushing the technology despite some optimistic claims of at least an order of magnitude reduction. A most important contributor to achievement of pointing accuracy is the FHST and a significant trade study was performed to select the FOV, star magnitude sensitivity, and configuration to assure enough navigation stars while retaining the specified accuracy. For the baseline FHST, the ± 0.5 arc min represents a worst-case error when a 6th magnitude guide star is tracked at the extreme edge of the 6 degree FOV. For performance flexibility, the system can fail down to one FHST, one reference gyro per axis, and three CMGs without degradation below required performance. An alternate operational mode using one of the two DSSs and any one of the four FHSTs can serve as a backup mode after star tracker failures or for the rare occasions that a reference star is unavailable for a desired pointing direction. For the sensing system, this permits failure down to one FHST, one reference gyro per axis, and one DSS with only slightly degraded performance.

The nonlinear characteristics of the CMGs (such as friction, deadzone, and tachometer properties) and the stability of the star trackers provide the major source of pointing stability errors. Using the nonlinear terms specified for the baseline CMGs, both analysis and computer simulations have shown a 2 to 5 arc sec pointing direction change as the gimbal torquers reverse direction. Since this is sensitive to system gains and CMG compensation, the actual stabilization error contributed by the CMGs should have considerable growth potential as the vehicle design and hardware characteristics become firm. The stability of the FHSTs was estimated to be in the range from a nominal value of 2 arc sec to an ultimate value of 0.4 arc sec. For both the CMGs and FHSTs, the jitter rate contribution is considerably less than the required 1 arc sec/sec.

TABLE V-10. ASCS REQUIREMENTS VERSUS CAPABILITIES

Design Requirement	Critical Design Features	Performance Capability	Performance Flexibility	Growth
Pointing Accuracy: ±1 arc min	FHST, CMGs	$\pm\frac{1}{2}$ arc min	Fail down to 1 FHST/axis, 1 gyro/axis and 3 CMGs without performance degradation. Fail down to 1 FHST, 1 gyro/axis and 1 DSS as sensors gives only slightly degraded performance.	Gimballed star trackers to improve pointing performance.
Pointing Stability: Good	CMGs, FHST	≈2 to 5 arc sec/$\frac{1}{2}$ orbit		
Jitter Rate: 1 arc sec/sec	CMGs, Gyros	<1 arc sec/sec		
No. of Manuevers >3600	CMGs	>3600	No. of maneuvers generally limited only by RCS fual available for CMG desaturation.	Additional RCS fuel or use of residual OAS fuel.
Reliability	No single point failures	0.945 at 1 year 0.810 at 2 years	Using redundant functional paths, failure modes of operation are available with the specified hardware complement to meet the 0.945 at 1 year and 0.810 at 2 years reliability goals.	Use a dodecahedron gyro arrangement for the RGA. Add 1 or 2 standby CMGs. Add 1 star tracker per axis. The alternate system with magnetic coils will permit more CMGs to fail.

Assuming worst case environmental torques, approximately two orbits are available before the system saturates and momentum must be dumped. However, with one CMG failed, the remaining three CMGs can be saturated in slightly less than one orbit, requiring either a more frequent dump than once per orbit or spinning up the CMGs to the higher level of 8000 rpm to produce more momentum per wheel.

With all CMGs operational, many computer runs were made to establish maneuver response capability. For normal HEAO-C operation, relatively small maneuvers are required about the solar pointing or Z-axis (Fig. V-17) although several runs were made similar to that required for HEAO-A (such as spinup to 0.1 rpm). In all cases, HEAO-A performance requirements were met with a wide margin. In the case of unusual maneuvers, such as "flare" viewing, the spacecraft could be rotated about the Y-axis by 90 degrees. Normal maneuvers were satisfactorily conducted at maneuver rates up to 20 degrees per minute. If required, more than 3600 maneuvers can be attained for the baseline HEAO-C design with the only constraint being the limit of RCS fuel available for CMG desaturation.

Since reliability was utilized as a guide throughout the conceptual design process, adequate redundancy and avoidance of single point failures are inherent in the baseline HEAO-C design. Using the available redundant functional paths, failure modes are available with the specified hardware complement to meet the reliability goals of 0.945 at one year and 0.810 at two years.

The maximum thrust required of a REA occurs during OAS burn. Assuming a worst-case main engine misalignment and other disturbing torques, the REA corrective thrust required is 2.4 pounds in a given plane. At the beginning of the mission, 10 pounds of thrust is available in the pitch, roll, and yaw axis. This value decreases to five pounds thrust toward the end of the mission. The maximum number of pulses required of any one REA for the HEAO-C mission has been determined to be about 145 000 with a total impulse approaching 18 000 lb-sec. Each REA is now qualified for 175 000 pulses and 18 000 lb-sec of impulse. The minimum impulse bit (MIB) capability of the REA is 0.15 lb-sec and the specific impulse range is 125 to 205 seconds.

The REAs will normally operate under a low-duty cycle during the HEAO-C mission and a continuing demand will be placed on the REM active thermal control system. This system must maintain REA temperature within acceptable limits to provide peak performance, conserve fuel, and, most important, prolong catalyst bed lifetime. Therefore, it is important that the active thermal system of the REM be qualified for the two year lifetime.

Should the HEAO-C propellant budget grow, or more propellant redundancy be required, the number of RCS tanks can be increased to nine and manifolded to the OAS tank. The OAS tank capacity approaches 3000 pounds; part of this propellant would be used for orbit adjustment of the HEAO-C and the remainder could be used for RCS control.

3. Commonality (Table V-11). There are two key differences between the HEAO-C and HEAO-A and -B that lead to basic hardware and software requirement differences. First, the HEAO-C is designed for a pointing mission only, and second, the accuracy required for the HEAO-C is greater. Generally, the items specified for HEAO-C can serve for the HEAO-A and -B with suitable software, physical location, and orientation modifications. The cost impact of the latter approach should be minimal, but in most instances means raising the initial funding required for the complete HEAO program with a corresponding funding reduction as the HEAO-C phase is entered. From an overall cost standpoint, the most efficient approach would be to let the HEAO-C requirements be the general driver on system design and hardware selection. Typical examples are star trackers, CMGs, and onboard computers.

TABLE V-11. COMMONALITY — ASCS

Definitions:

Category 1: Difference is due to design requirements — HEAO-A and -B can utilize HEAO-C approach but not vice versa.

Category 2: Difference is caused by design improvement — HEAO-C can utilize HEAO-A and -B approach but considerable impact will result in some cases — vice versa would be preferable.

Category	Design Requirement or Driver	Design Characteristic	HEAO-C	HEAO-A, -B[a]
1	Pointing Accuracy	Star Tracker Error	0.5 arc min	4 arc min
1	Pointing Accuracy	Gyro Drift Compensation	0.015 deg/hr random	0.1 deg/hr (estimate)
1	Pointing Accuracy	CMG Steering Law	Pseudo Inverse	3-Gimbal Inverse
1	Pointing Accuracy	Feedback Gains	High	Low
1	Life/Reliability	No. of CMGs	4 or 5	4
1	Momentum Management	CMG Desaturation	RCS, once per orbit	RCS, anytime
1	Antisolar Maneuver	CMG Size	High Torque	Low Torque
1	Maneuver/Spinup	Actuator Size	CMGs/CMGs	CMGs/RCS
2	CMGs	Mounting Configuration	Z-Axis Symmetry	X-Axis Symmetry
1	Life/Reliability	RCS Fuel	High	Low
1	RCS Reliability and Lifetime	RCS Plumbing Arrangement	Propellant Line Cross-Strapping Provided	Alternate Propellant Lines Limited
1, 2	RCS Reliability, Lifetime and Cost	Thruster Module Design	4 Thrusters per Module (Identical to LMSC SSC)[b]	3 Thrusters per Module and Added Series Redundant Thruster Valve; Modifications Increase Cost.
1, 2	RCS Reliability, Lifetime and Cost	Thruster Module Location	2 Modules Together, 180 deg Mounting Location Separation	Modules 90 deg Apart
1	RCS Reliability and Lifetime	Isolation Valves, Type and Quantity	Isolation Provided for Each Tank and Each 2 Thrusters; Solenoid Type Valves Provide Return Capability	Each Tank not Completely Isolatable; Squib-Type Valves Limit Return Capability.
1	Large No. of Sources	Digital Computer on Board for Attitude Calculations	Onboard Computation	Ground Control Feasible

a. *The data in this column represent either the Phase C/D statement of work requirement or the most applicable* Phase B study concept, whichever was deemed most appropriate for the consideration at hand.

b. Lockheed Missiles and Space Company Satellite Control Section.

The difference between the RCS hardware components proposed for HEAO-A and -B and those proposed for HEAO-C is minimal.

D. Electrical System

The electrical system integrates spacecraft subsystems and OAS equipment into one functional system. Power is generated, controlled, and distributed redundantly to the various experiment and subsystem assemblies by conventional cabling networks emanating from several distribution assemblies. Power is delivered to each load at 28 ±2 percent volts dc. Spacecraft electrical interfaces with the OAS, the launch vehicle, and the electrical support equipment (ESE) are provided.

Internal electrical equipment, shown in Figure V-19, was located for thermal compatibility within the spacecraft, accessibility, and short cable runs. The major equipment comprising the electrical system is listed in Table V-12. The OAS electrical equipment weight is included in the OAS weight.

Primary power is furnished by a conservatively designed solar array. The six rechargeable, NiCd batteries and charger assemblies permit energy storage during sunlight periods of the orbit and power the system during occultation. Primary and secondary power is conditioned by redundant regulator assemblies.

A simplified schematic of the electrical system is shown in Figure V-20. Except for solar array capacity, the system is completely redundant, physically and electrically. Extensive studies were made to assure that single point failure modes were eliminated, and the reliability goal of 0.92 for two years was exceeded. Short circuit and open circuit fault protection are provided. All loads are protected from over-voltage and faults in other loads. All critical functions may be monitored from the ground and command overrides are provided.

Flexibility is provided by the various operational modes possible, e.g., various combinations of batteries and regulators can be used to supply the redundant load buses. Modular system and assembly concepts permit optimization for and adaption to other missions or requirement changes. The versatile electrical integration assemblies will accommodate variations in experiment complement without major impact on the spacecraft systems.

1. <u>Component Description.</u>

a. Solar Array. Since the system has a performance factor of 2.14, the solar array must have a minimum end-of-mission (EOM) rating of

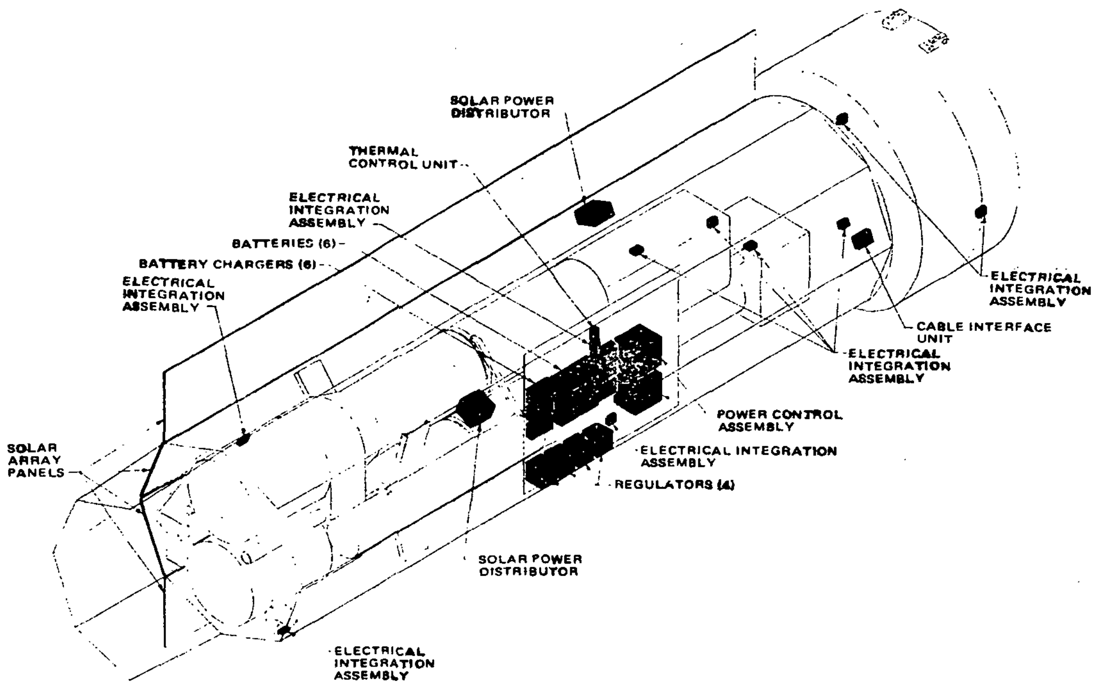


Figure V-19. Electrical system assembly locations.

TABLE V-12. HEAO-C ELECTRICAL SYSTEM EQUIPMENT

	No. of Assemblies	Unit Weight (lb)	Unit Size (In.)	Thermal/Orbit Dissipation (Avg. Wh)	Total Weight (lb)
Spacecraft Equipment					
Solar Distributors	2	18	13 × 11.5 × 6.75	35[a]	36
Electrical Control Assembly	2	16	14 × 8 × 8	30	32
Electrical Integration Assembly	8	2.5	6 × 4 × 3	7	20
Regulator Assembly	4	8	11 × 8 × 5	125	32
Charger Assembly	6	14	11 × 8 × 6	30[a]	84
Battery	6	52	13.1 × 6.7 × 7.4	123	312
Cable Interface Unit	1	8	9 × 6 × 2	0	8
Solar Array					
Wing Panels	6	36.1	119 × 38.2 × 0.7	N/A	217
Body Panels	2	32.2	119 × 38.2 × 0.7	N/A	65
Deployment Hardware	6	8.4		N/A	50
Cabling				25[b]	125
Spacecraft Subtotal					981
OAS Equipment					
Electrical Integration Assembly	2	2.5	6 × 4 × 3	1	5
Pyro Battery (Primary Type 31)	1	16	LMSC[c] Item	N/A	
Pyro Junction Box	1	6	LMSC Item	N/A	Weights are
OAS/RCS Junction Box	1	12	LMSC Item	14	
Instrument Junction Box	1	4	LMSC Item	2	Included in
Umbilical	1	9	LMSC Item	N/A	
Cabling		50		2	OAS Weight

a. Dissipation average for sunlight period only.
b. Internal cabling dissipation is 15 Wh.
c. Lockheed Missiles and Space Company.

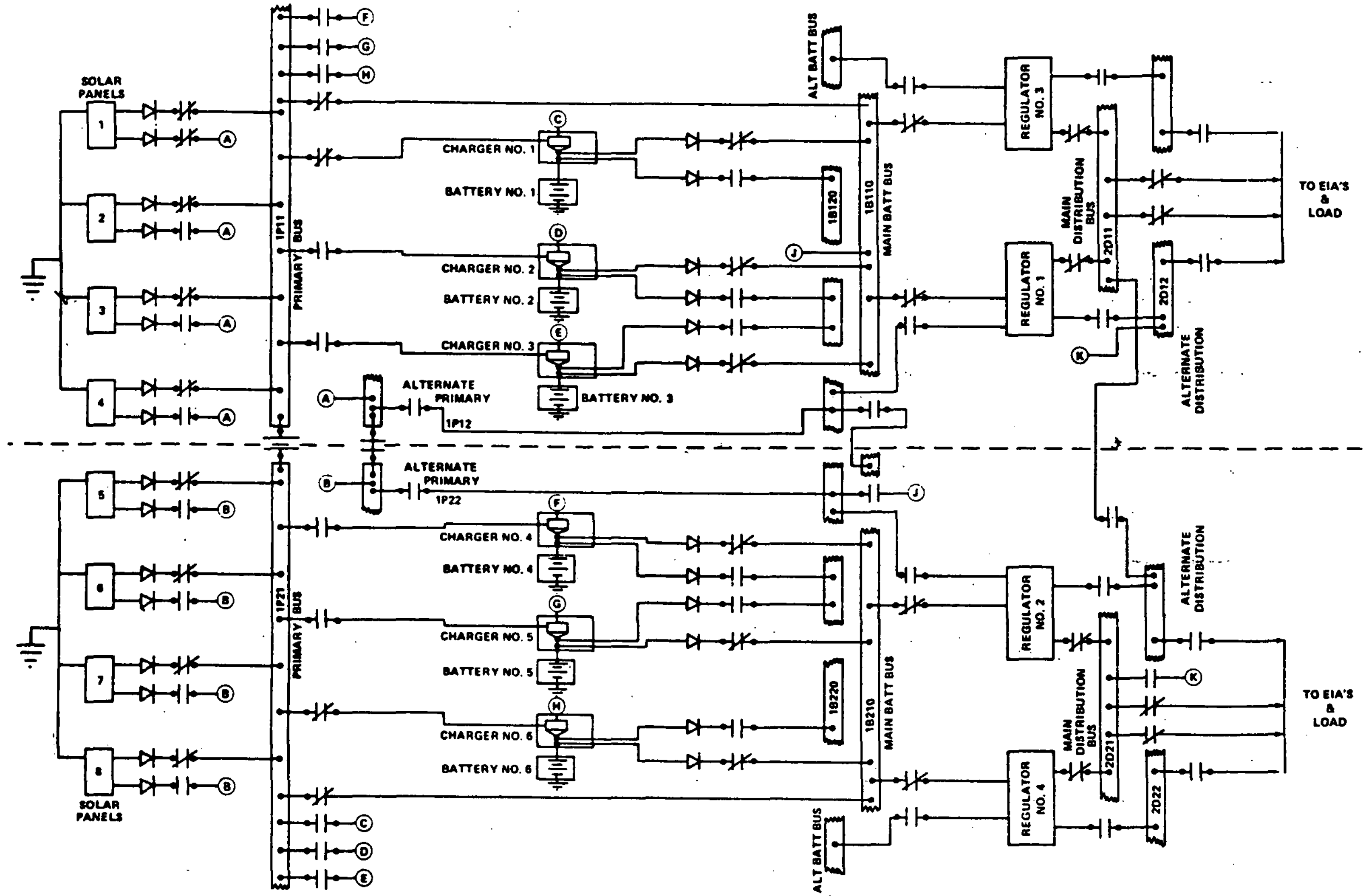


Figure V-20. Electrical power system schematic.

1549 watts to satisfy the load, battery charging, and system loss requirements. The solar array has an area of 253 square feet and consists of 6 wing panels and 2 body-mounted panels as shown in Figure V-21. All panels are electrically identical. The body panels use a lower stacking factor to maintain a lower cell temperature. The array is comprised of 22 220, two ohm-cm solar cells (2 × 4 cm), mounted on aluminum honeycomb substrates. The array size is adequate to meet the spacecraft power requirements even if one panel fails to deploy. A full array, when deployed, can supply the loads up to a 40 degree off-sun angle. Greater off-sun angles can be supported if the time is limited. Use of foldout panels reduces the solar array temperature and permits the use of fewer cells, for an overall increase in efficiency and reliability with a decrease in array cost. Redundant deployment mechanisms assure array deployment. Each of the six wing panels is individually deployed, using a separate primary battery supply. Redundant deployment mechanisms may be initiated by onboard logic, or by ground command. Table V-13 summarizes the solar array characteristics and ratings.

b. Energy Storage Subsystem. Energy storage is furnished by six 24-cell NiCd battery assemblies, using 20 Ah cells. The battery cases are designed for 10° ±5° C temperature control, to extend battery life. The batteries operate at a 14.3 percent depth of discharge, and have a life expectancy of at least 16 000 cycles. Each battery has a dedicated charger assembly, which provides temperature compensated, I-V characteristics tailored to the battery characteristics for maximum charge efficiency and life. The chargers will limit the maximum charge/discharge rate to less than rated current for the batteries. Charge is terminated by third electrode signal or by the ampere-hour meter. Table V-14 summarizes the battery characteristics.

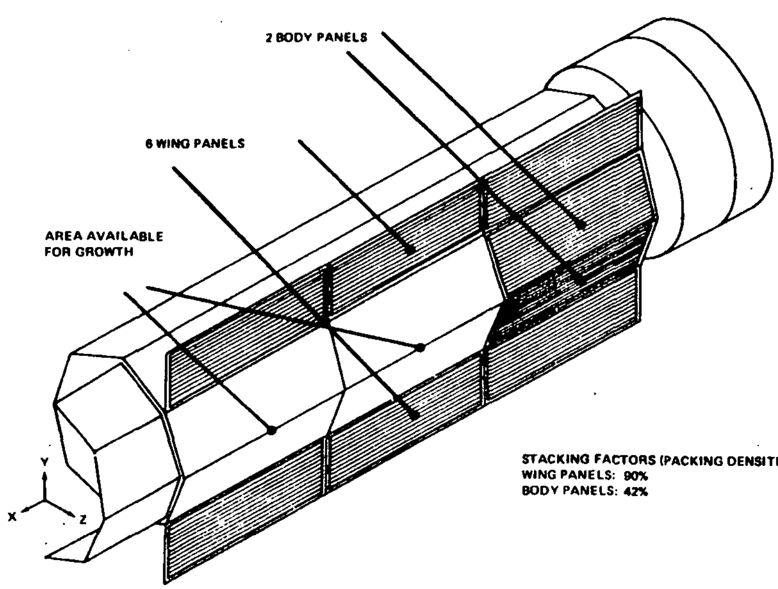


Figure V-21. Deployed baseline solar array.

TABLE V-13. BASELINE SOLAR ARRAY SUMMARY

Electrical Ratings						
Mission Time	BOL			EOM		
Orientation Off Sun (deg)	0	15	30	0	15	30
Rated Avg. Power (for 59 min) (W)	2060	2014	1864	1881	1834	1695
Required Avg. Power (W)	1549	1549	1549	1549	1549	1549
Design Margin (W)	511	465	315	332	285	146
Max Power (W)	1915	1850	1660	1760	1700	1525
Peak Voltage (Open Circuit)	78			75		
Operating Point Min Design Voltage	38			38		
Continuous Off-Sun Pointing Capability (deg)	48			40		

Physical Characteristics	
No. Array Panels (Total)	8
Wings (Foldout)	2
Panels per Wing at 90% Stacking Factor	3
Body Panels at 42% Stacking Factor	2
Total Array Panel Area	253 ft^2
Total Panel Weight	275 lb
Substrates	0.7 in. Al honeycomb
No. Cell Assemblies (With 110 series cells)	70
Cell Type	N/P Silicon - 2 ohm - cm
Cell Size	2 × 4 cm
Cell Thickness	14 mils
Rated Cell Efficiency	11%
Total No. Cells	22 220
Cover Slides (Coated)	6 mils
Temperature Rating	-40° C to + 100° C
Operating Temperature Range	-25° C to + 83° C
Deployment Mechanism	Torsion Rods/Dampers
Restraint Release (Wings)	Redundant Pyro Bolts
Deployment Hardware Weight	50 lb

TABLE V-14. ENERGY STORAGE SUBSYSTEM BATTERY ASSEMBLY CHARACTERISTICS

Characteristic	Subsystem Total	
General		
Battery Assemblies	6	
Cells	132	
Type	Secondary Ni-Cd	
Style	Hermetically Sealed	
Nominal Rating Class	20 Ah	
Electrical Interface	MS Connectors	
Physical		
Weight	312 lb	
Volume	3870 $in.^3$	
Temperature	10 ±5° C	
Thermal Dissipation	123 Wh	
Electrical	**Required**	**Rated**
Avg. Energy	482 Wh	3360 Wh
Max Energy	502 Wh	3804 Wh
Discharge Voltage	22 to 33 Vdc Permitted	24 to 29 Vdc
Charge Voltage	29 to 33 Vdc	29 to 33 Vdc
Peak Load	1375 W	3300 W
Max Current	56 A	120 A
Cycle Life	11 080	16 000
Performance Factors		
Depth-of-Discharge (DOD)	≤ 15%	14%

c. Regulators. Power is regulated by the regulator assemblies to 28 ±2 percent volts. The regulators are transformer coupled, switching types with a demonstrated efficiency of better than 90 percent. Any two of the four assemblies can regulate the normal spacecraft load. The regulators also provide overload protection and load isolation functions.

d. Solar Power Distributors. Power from the solar array is collected, controlled, and distributed by the solar power distributors. They also control array deployment and perform array instrumentation functions. Provision is made for the performance of dark I-V tests of solar array characteristics on the ground, before flight.

e. Electrical Control Assembly. The electrical control assemblies centralize the electrical system control, distribution, and instrumentation functions. The main distribution buses are controlled and protected from faults by the ECA. They also provide a common point ground for the entire spacecraft. The main distribution buses are redundant and furnish power to critical loads and to the electrical integration assemblies.

f. Electrical Integration Assembly (EIA). The EIAs are remote load distributors that provide secondary protection and control. Interfaces with the command subsystem provides each load access to redundant power distribution buses by command.

g. Cable Integration Unit (CIU). The CIU is the electrical interface between the HEAO and the OAS. Prelaunch access to the HEAO is provided through the CIU. Figure V-22 illustrates the HEAO/OAS interface functions to be accommodated.

2. Requirements versus Capabilities. The electrical system baselined for HEAO-C effects commonality with HEAO-A/B missions and exceeds the performance requirements established. Flight proven technology, existing modular designs, and qualified components have been specified throughout to minimize cost and development risks.

Electrical power requirements are illustrated by the typical power profile of Figure V-23. System power requirements are summarized by subsystems for two mission phases in Table V-15. Including a 14 percent contingency for load growth, an orbital average of 722 watts and a peak of 1238 watts were required.

A system requirement dictated off-sun pointing of the spacecraft Z-axis, 15 degrees continuously and 30 degrees for one orbit per day. The system performance ratings at the beginning of life (BOL) and the end of mission (EOM) are compared with requirements in Table V-16.

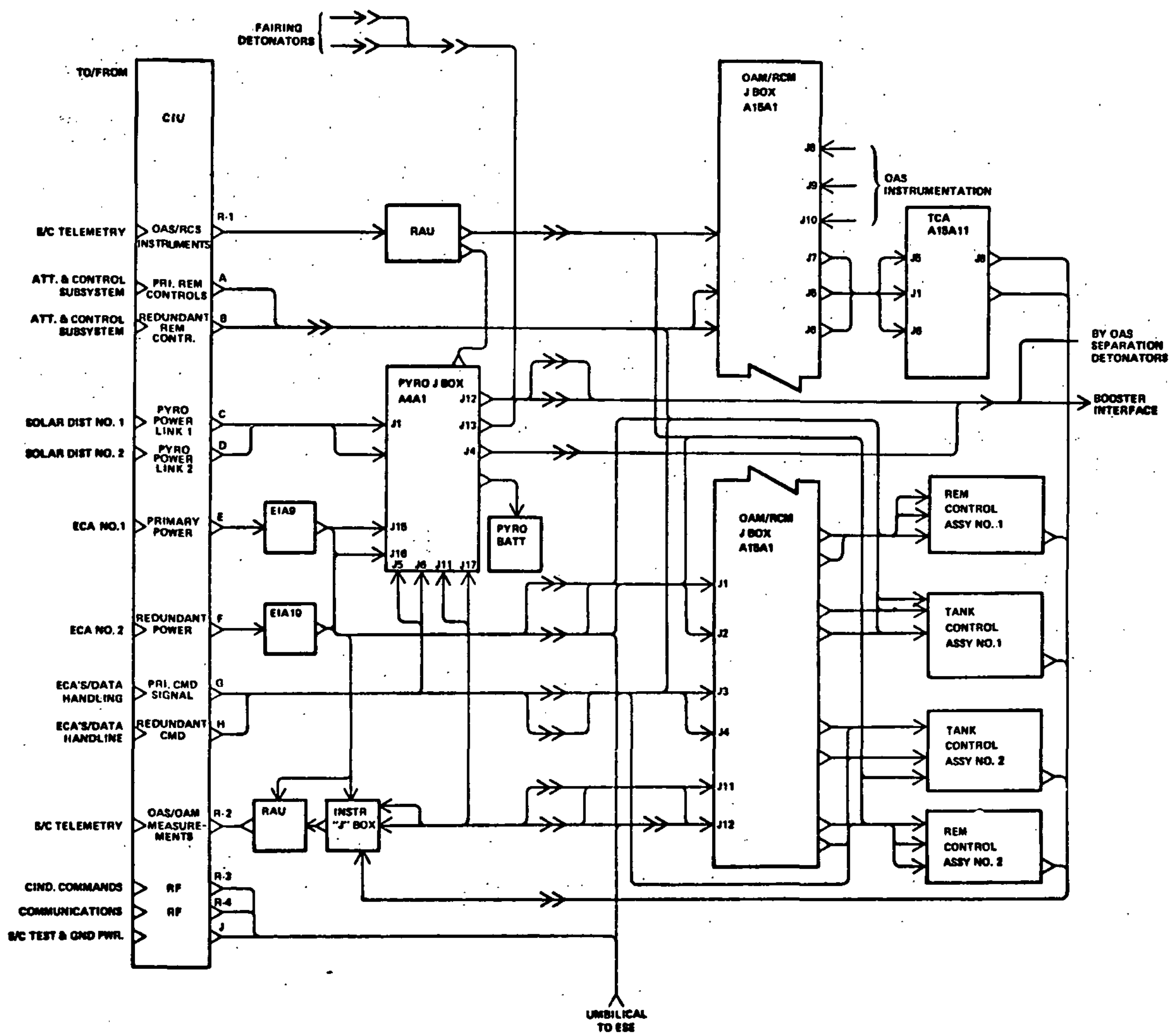


Figure V-22. Modified OAS cable interconnect drawing.

3. Trade Studies. The selection of the baseline electrical system was based on numerous subsystem trade studies, reported in Appendix F of Volume III. Of the three solar array configurations, the baseline offered the lowest temperature, highest cell efficiency, and largest growth potential. Three sizes of battery cells and several assembly sizes were considered to optimize redundancy and reliability for system capacity and low weight. Several regulator designs were analyzed. System performance analyses included variations in load and temperature conditions and considered the effects of abnormal operating conditions.

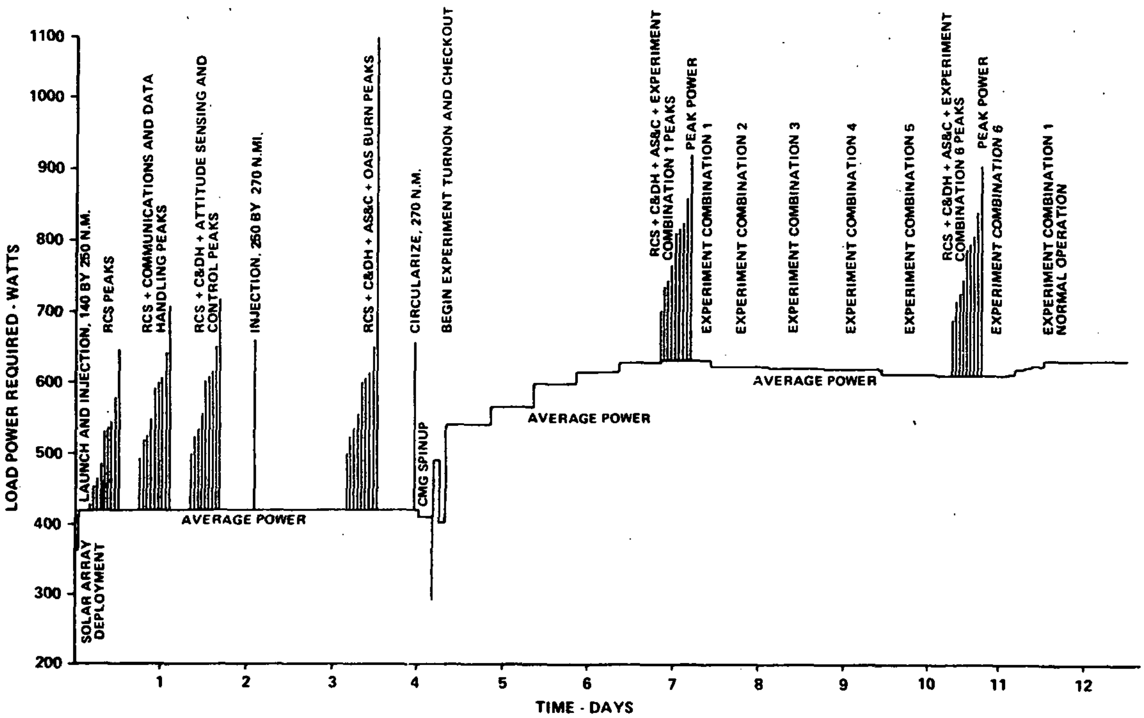


Figure V-23. HEAO-C power profile.

TABLE V-15. SUMMARY OF POWER REQUIREMENTS FOR MISSION C OPERATION IN LOW ORBIT AND HIGH ORBIT

Load	Operation in Low Orbit		Operation in High Orbit	
	Average Power (W)	Peak Power (W)	Average Power (W)	Peak Power (W)
Experiments	a	a	234.0	294.0
Communications and Data Handling	79.3	141.6	79.3	141.6
Attitude Sensing and Control	139.1	144.1	252.1	353.1[b]
Thermal Control	10.0	40.0	10.0	40.0
RCS	41.9	295.0	41.9	295.0
OAS	133.0	367.0	c	c
Electrical System	16.0	25.0	16.0	25.0
Baseline Subtotal	419.3	1012.7	633.3	1148.7
Contingency (14%)[d]	59.0	59.0	89.0	89.0
Total	478.3	1071.7	722.3	1237.7

a. Not used in low orbit
b. Assumes simultaneous spinup of all CMG's
c. Not used in final high orbit
d. Suggest 20 percent contingency for follow-on Phase B effort

TABLE V-16. HEAO-C ELECTRICAL SYSTEM CHARACTERISTICS AND PERFORMANCE RATINGS

Characteristic \ Pointing Condition (deg)	Mission Time: BOL 0	BOL 15	BOL 30	EOM 0	EOM 15	EOM 30
Avg. Load Requirement (W)	722	722	722	722	722	722
Rated Avg. Power (W)	963	941	871	879	857	792
Design Margin (Avg. W)	241	219	149	157	135	70
Peak Load Required (W)	1238			1238		
Peak Output Power Rating	1800			1800		
Continuous Off-Sun Pointing Capability (15 deg required)	48 deg			40 deg		
Nominal Output Voltage	28 Vdc					
Regulation	± 2%					
System Efficiency	75.3%					
Performance Factor	2.14					
Minimum Life	2 yr					
Predicted Reliability	0.992 at 1 yr, 0.944 at 2 yr					

4. Commonality. Commonality was considered essential to minimizing cost and development time and risks. With minimum experiment adaptions, the baseline electrical system is capable of performing HEAO-A/B missions, although it would be somewhat oversized. Experiment configuration could affect spacecraft configuration and require relocating the solar array. Conversely, the electrical system designed for the HEAO-A/B spacecraft can be easily modified to provide the additional power required for HEAO-C. The power control scheme developed for HEAO-A/B will satisfy HEAO-C since there are no inherent differences in regulation requirements.

The HEAO-C system design concepts are based on proven technology, existing modular designs, and qualified components.

E. Communication and Data Handling System

The communication and data handling system, with the exception of tape recorders, can be classified as existing technology. Omnidirectional antenna coverage is accomplished using frequency diversity on both transmitter and receiver links. Two antennas are employed, operating at different frequencies and located on opposite surfaces of the spacecraft. This is necessary because of the large diameter of the spacecraft and the high operating frequency (S-band). The transponders contain both transmitters and receivers. The downlink frequency of one of the transponders is derived from the uplink frequency. The other is obtained from an internal crystal oscillator. The onboard command system is a decentralized decoder with a central storage for delayed commands. Data acquisition is by remote multiplexers under control of a central unit. All the data are digitized at the remote multiplexer and are provided to either the communication system or the data storage equipment as digital words. Four tape recorders are used to store both experimental data and engineering data when the Observatory is not in view of a ground tracking station. Major design features, component locations and block diagram, and component characteristics are given in Figures V-24 and V-25 and Tables V-17 and V-18.

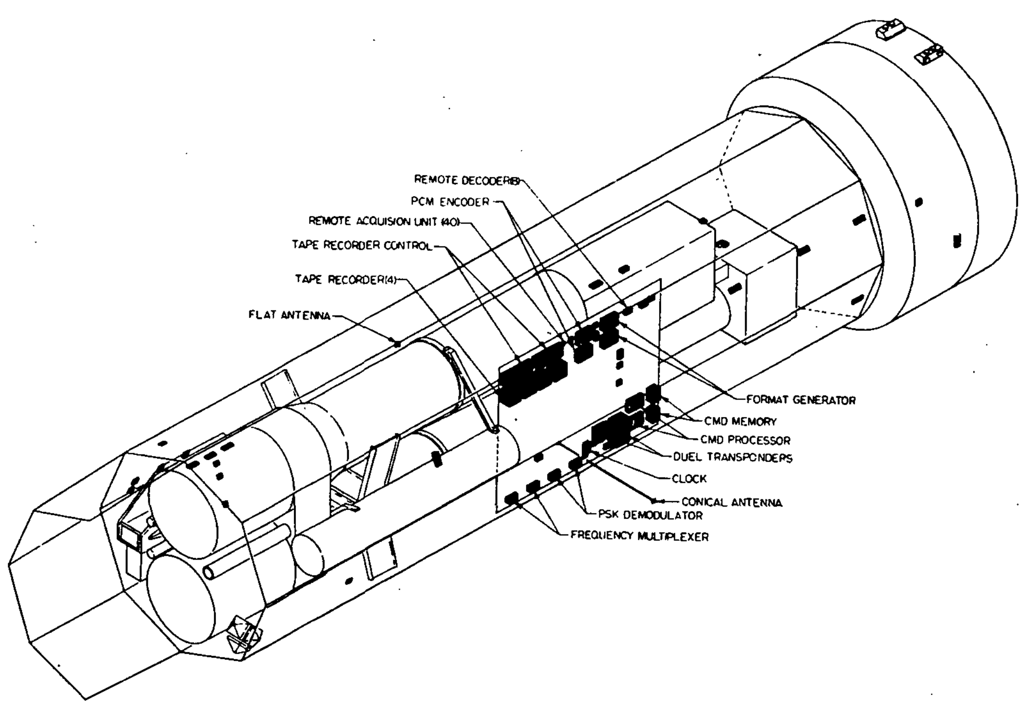


Figure V-24. C&DH system component locations.

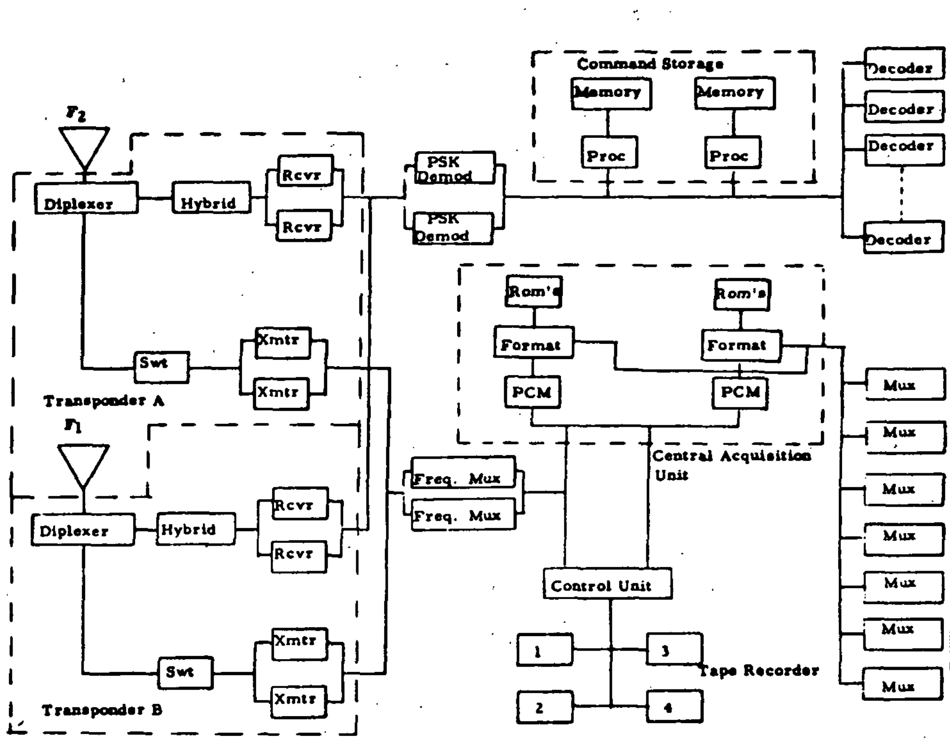


Figure V-25. Baseline C&DH system block diagram.

TABLE V-17. MAJOR DESIGN FEATURES OF HEAO-C C&DH SYSTEM

- Omnidirectional Antenna
- Frequency Diversity Transmission and Reception
- Remote Acquisition of Data
- Decentralized Command Decoding
- Highly Reliable, Long Life Tape Recorders
- Proven Technology
- Near-Perfect Commonality with HEAO-A/B

TABLE V-18. C&DH COMPONENTS IN THE EQUIPMENT COMPARTMENT

Item	Weight (lb)	Peak Power (W)
Transponder (2 ea.)	48.0	56.0
Frequency Mux (2 ea.)	2.0	4.0
PSK Demodulator (2 ea.)	2.0	0.8
PCM Encoder (2 ea.)	8.0	6.4
Format Generator (2 ea.)	7.6	4.2
Command Processor (2 ea.)	4.0	15.6
Command Memory (2 ea.)	12.0	7.0
Remote Mux (40 ea.)	12.0	1.2
Remote Decoder (8 ea.)	8.0	1.4
Data Storage Control (2 ea.)	3.0	1.0
Tape Recorder (4 ea.)	60.0	30.0
Clock (3 ea.)	3.0	14.0
Total	169.6	141.6

1. Component Description.

a. Antennas. Two types of antennas are used on the Observatory. The antenna on the antisolar side is boom-mounted and a conical spiral type. The antenna on the solar side is surface-mounted to preclude shadowing the solar array. A cavity-backed spiral was selected for this application.

b. Transponder. The two transponders are identical in design even though they operate at different frequencies. The units are being designed and built for the Earth Resources Technology Satellites (ERTS). Each unit is comprised of two transmitters and two receivers with diplexing and control circuits. The all-solid-state design is a derivation from the previous Apollo USBE Transponder and is therefore compatible in all respects with the Manned Space Flight Network (MSFN).

c. Command Storage. The command storage contains a plated wire memory and a processor. The plated wire memory is a low power, high reliability $2\frac{1}{2}$D organization (see Volume II, Chapter IX). It uses the same construction techniques employed in the transponders. The design of the processor is customized for this specific application. It contains logic circuits to distinguish between real-time commands and stored commands, continually cycling the memory for comparison with the clock and, at the proper time, shifting commands onto the bus.

d. Data Acquisition System. The data acquisition system consists of a central unit comprised of a format generator, read-only memory (ROM), and PCM logic circuits to generate commands and timing to the 40 remote digital multiplexers. The format generator and ROM determine the order and frequency in which the remote unit will be interrogated. The PCM equipment acts as the input/output unit of a digital computer.

e. Data Storage System. The four tape recorders are longitudinal, coaxial, reel-to-reel machines. The design, as depicted in Figure V-26 does not exist at this time. It is a composite of tried and proven component and state-of-the-art developments such as a Kapton belt, dc brushless motor, improved negator spring, ferrite core heads with alpha-sil, and nonmagnetic pole tips. The differential, capstan, and tape guides have been used in space-qualified recorders. Tape recorders developed for the HEAO-A/B spacecraft must employ similar design features and should satisfy HEAO-C requirements.

f. Clock. The timing pulses used throughout the Observatory are supplied by a group of countdown chains that are referenced to a crystal-controlled oscillator in a thermal-controlled oven. The clock contains three

such oscillators: two are phase-locked together, while the third one is standby. This is necessary to maintain continuity in the event of a failure of either oscillator. Several hours are required for the oscillator to stabilize after oven heaters are turned on.

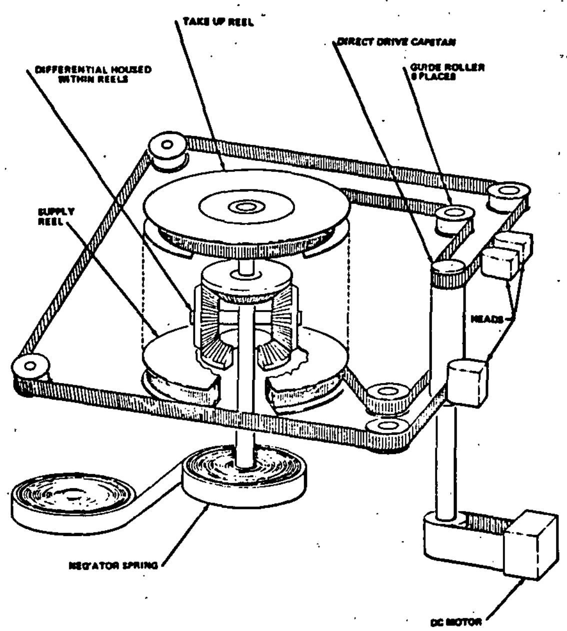


Figure V-26. Tape recorder transport schematic.

2. Requirements Versus Capabilities. The requirements column of Table V-19 represents the significant values that influenced the conceptual design. Certain values were groundruled or assumed at the beginning of the study to be compatible with either the experiments or the ground stations. The bit error rate and false command figure are indicative of good design practice. At first glance it appears that the command system is overdesigned. The ground station high power transmitter provides a -65.5 dBm signal at the input to the receiver. The dynamic range of the receiver is from -46 to -126 dBm. The -65 dBm signal strength is well within this desired range. Reduction of ground-based transmitter power would not result in any design changes in the Observatory.

The Observatory clock is not maintained in synchronization with a terrestrial standard; however, the design does permit correlation in an indirect manner. A time code from the ground station standard is provided on the data recording, along with position data of the spacecraft with respect to the station. The station standard can be calibrated to within 100 microseconds of either the National Bureau of Standards or the Naval Observatory. This would permit earth observations to be correlated with the orbital Observatory sightings.

A comparison of the requirements and capability columns of the tape recorder indicates that three, rather than four, recorders would have been adequate; however, the developmental nature of the component motivated the additional unit in the baseline design.

The reliability number of the communication system seems high but results from the redundancy inherent in the design of the transponder. Possibly one dual redundant transponder would have been sufficient from the

TABLE V-19. REQUIREMENTS VERSUS CAPABILITY

Parameter	Requirements	Capability	Margin
Antenna	Omnidirectional	0 dB or better over sphere	
On-board Data Rate	24.5 kbs	27.5 kbs	3 kbs Growth
Bit Error Rate	1×10^{-5} (S/N = 13.35 dB)	1×10^{-7} (S/N = 14.89 dB)	1.5 dB Margin
False Commands	< 1 in 10^{9} S/N = 7 dB ($2. \times 10^{-18}$) Real-time	47.5 dB	40.5 dB Margin
	S/N = 7 dB ($6. \times 10^{-17}$) Stored	47.5 dB	40.5 dB Margin
Command Sub-Bit Error Rate	3×10^{-4} S/N = 7 dB } Real-time	47.5 dB	40.5 dB Margin (sub-bit rate may be increased considerably)
	3×10^{-4} S/N = 7 dB } Stored	47.5 dB	
Compatible with MSFN (Unified S-Band)	500 kbs Baseband 24.5 kbs Subcarrier	500 kbs Baseband 200 kbs on 1.024 MHz subcarrier Voice on 1.25 MHz subcarrier	175 kbs growth
Clock	1 part in 10^{9} per day reference to GMT	S/C osc stable to 5×10^{-9} per 24 hr Ground station standard sync to WWV or LORAN-C to within 100 microseconds	Data tapes can be correlated to meet this requirement
Tape Recorder Bit Rates Capacity	 24.5 kbs Record 500 kbs Playback 4.5×10^{8} bits	 10 kb/in. at 4 IPS = 40 kbs 10 kb/in. at 80 IPS = 800 kbs 6×10^{8} bits	 15.5 kbs 300 kbs 1.5×10^{8} bits (one recorder)

reliability point of view; however, two transponders were necessary for frequency diversity operation. This also provides a large degree of flexibility as far as "work around" modes in the event of failures in other elements of the Observatory.

The remote multiplexers and centralized command system contribute to the flexibility and growth potential of the entire Observatory. It minimizes experiment and spacecraft interface complexity. Subsystem design changes can be easily accommodated by rearrangement of jumper wires on the mission plug associated with a particular remote multiplexer.

The distributed commander decoder approach not only saves in weight as indicated in Figure V-27, but it has a much higher reliability. This higher reliability is due primarily to the fact that all remote decoders do not have to be functioning properly for a successful mission. The circuit complexity of any one of the remote units is considerably less than a central unit would be and redundancy can be provided at critical locations.

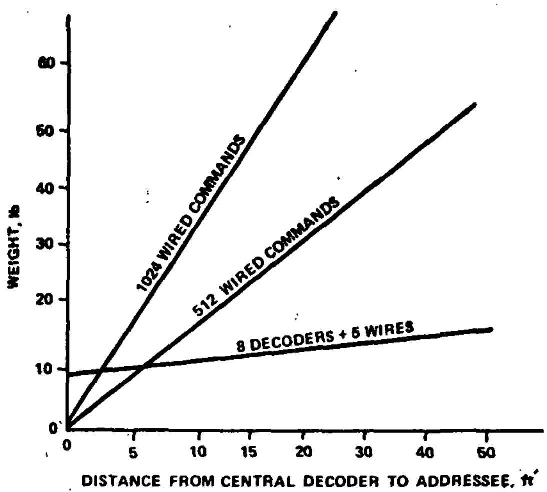


Figure V-27. Comparison of central and remote decoders.

3. Commonality. The components that comprise the communication and data handling system are nearly identical to those presently being considered for the HEAO-A/B mission, the one exception being the command storage elements of the command system. The HEAO-A/B mission does not require this capability. The command system will function for real-time commands without the storage capability. The only modification required to add the storage unit would be a wire for the PSK demodulator to the command processor with a pulse to indicate when the vehicle address had been decoded. This function would be performed in the PSK demodulators as a matter of decoding the uplink modulation, and could be brought out through a line amplifier without a great deal of expense.

The commonality of components may not increase the number of units to the point where production cost would be greatly reduced, but commonality would certainly reduce the engineering, design, and qualification testing which contribute largely to system cost.

CHAPTER VI. SPACE SHUTTLE LAUNCH AND RETRIEVAL

Although the Titan IIID/OAS was used as the baseline launch vehicle for the study, the impact of possible Shuttle launch and retrieval was briefly assessed. Shuttle design data were still very "soft" and changed frequently; however, several general conclusions were reached.

The assessment was performed from four different viewpoints, since each could have a significantly different effect on the design:

- Design for Shuttle-only launch.
- Design for Titan IIID/OAS-only launch.
- Design for either Titan IIID/OAS or Shuttle launch.
- Design for Shuttle retrieval.

The HEAO-C requirements, Shuttle capability, and Titan IIID/OAS capability are shown in Table VI-1 for a few key items of consideration. Table VI-2 and Figures VI-1 and VI-2 display additional Shuttle data used in the assessment.

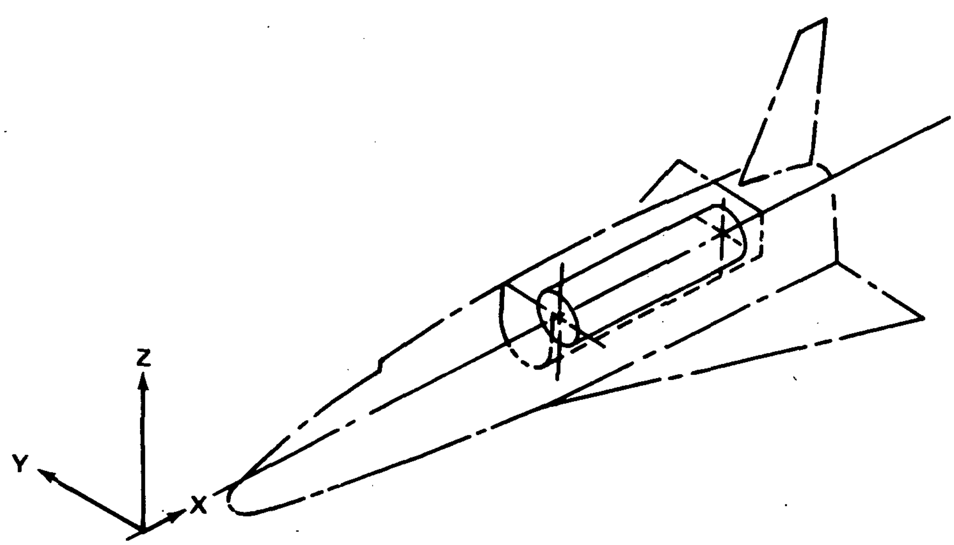
TABLE VI-1. HEAO-C/SHUTTLE/TITAN COMPATIBILITY

	Payload Bay Size (~ft)	Payload	Launch Acceleration	Allowable Dynamic Envelope	Payload Ejection Dynamics	Initial Payload Orbital Orientation	Max Acoustic Pressure Level
HEAO-C Requirements	9 × 30	19 000 lb to 270 n. mi. 28.5 deg inclination	Not specified	Not specified	Not specified	Not specified (solar vector desired)	Not specified
Estimated Shuttle Capability	15 × 60	30 000[a] lb to 270 n. mi. 28.5 deg inclination	1 g lat. max, 3.3 g long. max	±3 ft	Close to Zero	Anything desired	155 dB
Titan IIID/OAS Capability	≈9 × 47	24 000 lb to 270 n. mi. 28.5 deg inclination	1.5 g lat. max, 6 g long. max	Several inches	Approx. 3 deg/sec	Depends on ejection dynamics	165 dB

a. OMS ΔV = 1000 fps.

TABLE VI-2. SHUTTLE PAYLOAD LOAD FACTORS

Condition	X(g)	Y(g)	Z(g)
Launch	1.4 ±1.6	±1.0	±1.0
High Q Booster Thrust	1.9 ±0.3	±1.0	0.8 ±0.2
End Boost (Booster Thrust)[a]	3.0 ±0.3	±0.6	±0.6
End Burn (Orbiter Thrust)	3.0 ±0.3	±0.5	±0.5
Orbiter Entry	-0.5	±1.0	-3.0 ±1.0
Orbiter Flyback	-0.5	±1.0	+1.0 -2.5 ±1.0
Landing	-1.3	±0.5	-2.7 ±0.5
Crash (Nonintact Equipment Survival)[b]	-8 +1.5	±1.5	-4.5 +2.0



a. Excludes Booster-Orbiter separation loads which are to be determined.
b. Nonsimultaneous or -8.0 in 20 degree cone from N_x.

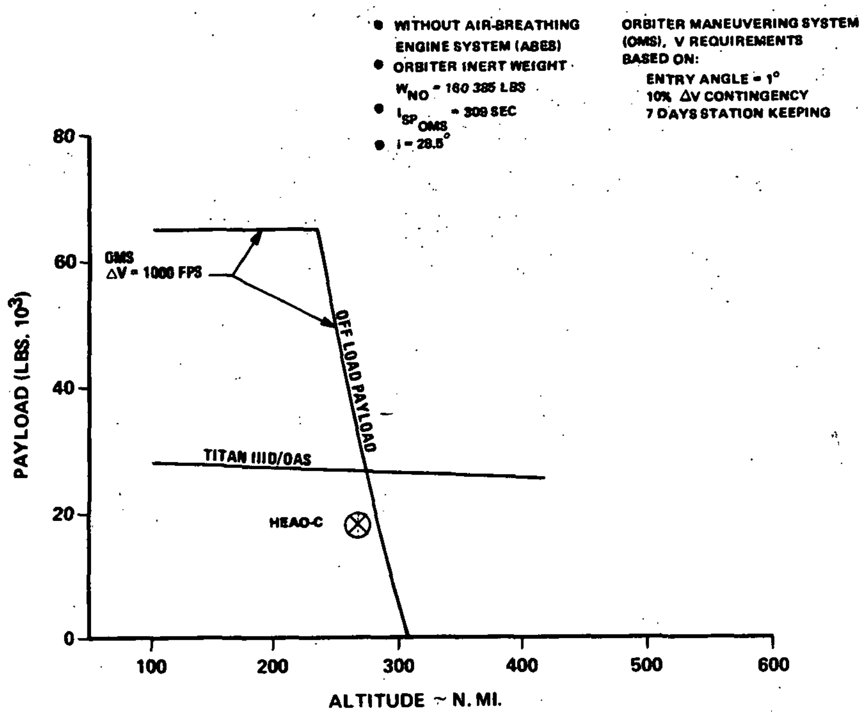


Figure VI-1. Launch vehicle performance capability.

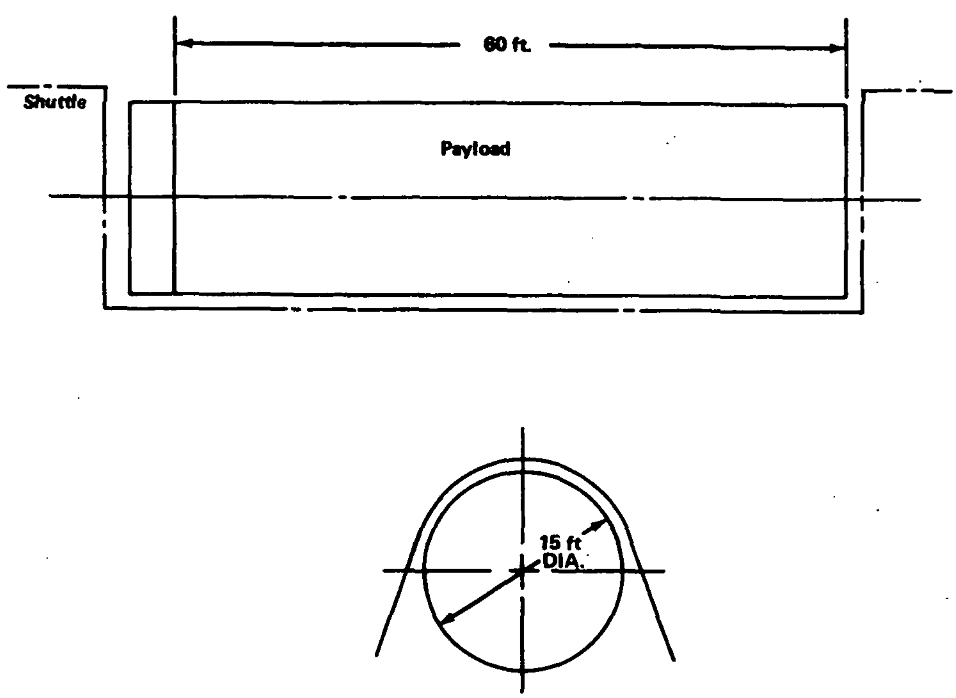


Figure VI-2. Shuttle payload envelope (typical).

A. Design for Shuttle-Only Launch

Increased payload capability in terms of both weight and volume together with lower launch acceleration levels and acoustic pressures would ease many of the baseline HEAO-C design constraints. Several fundamental design changes could be considered, such as elimination of the RCS in favor of a magnetic system for CMG momentum dump. However, all design changes must be carefully traded with regard to the following:

- The cost-effectiveness of diverging from established commonality with HEAO-A/B spacecraft.
- The considerable redesign and retest required should a later decision be made to launch on the Titan instead of the Shuttle.

B. Design for Titan IIID/OAS-Only Launch

Designing for launch on the Titan IIID/OAS generally imposes more severe constraints than designing for Shuttle launch. In general, should a later decision be made to launch on the Shuttle, modifications to the HEAO-C designed for Titan IIID/OAS launch are more easily effected than in the reverse situation. However, full advantage of Shuttle capabilities could not be salvaged without major modifications.

C. Design for Either Titan IIID/OAS or Shuttle Launch

Although current planning for the HEAO-C shows a launch date several years earlier than the planned operational availability of the Space Shuttle, changes might occur which would make this compromise option attractive. In all likelihood, the net impact on the HEAO-C design would also be a compromise. Much further analysis is required to identify the most cost-effective approach and much of this must await maturation of Space Shuttle design data. Also, decisions will be significantly influenced by guidelines involving Shuttle retrieval.

D. Design for Shuttle Retrieval

The HEAO-C is a candidate for Shuttle retrieval regardless of which launch vehicle places it into orbit. Clearly, if it has been designed for Shuttle-only launch, or possible Shuttle launch, many of the launch vehicle/spacecraft interfaces will have already been established and retrieval will be facilitated.

Three principal advantages accrue from designing for, and implementing, HEAO-C retrieval:

- Confidence in mission success is significantly enhanced. Should a major Observatory malfunction occur which degrades operational capability to such a low level that it is no longer cost-effective to continue orbital operations, the Shuttle makes possible retrieval, repair, and relaunch. Also, if Shuttle launched, on-orbit checkout during Observatory system activation is possible, and immediate retrieval can be implemented should a malfunction be detected during this critical period.

- Laboratory analysis of the effects of long lifetime in space environment will be possible. Subsequent to retrieval, HEAO-C experiments, materials, and subsystem components can be subjected to detailed laboratory testing to establish degradation levels and improve future lifetime and reliability estimates.

- Finally, retrieval opens up the possibility for refurbishment, replacement of focal plane detectors with different and newer instruments, and launching a second HEAO-C mission.

The design impacts associated with docking, retrieval, and return of the HEAO-C to earth will probably be greater than those associated with launch. This is true particularly of the docking design concept and the structural support concept for the lateral g-loading during reentry and landing. Table VI-2 shows a 4 g maximum lateral acceleration during orbiter entry, a higher lateral acceleration than for either Titan IIID/OAS or Shuttle launch.

Four docking concepts were investigated during the study. A cooperative HEAO-C was assumed throughout; much additional study effort is still required to establish the operational and design impacts associated with an uncooperative (tumbling) satellite, e.g., design for passive stabilization or active redundant backup stabilization systems.

CHAPTER VII. RECOMMENDATIONS

Throughout Volumes II and III, suggestions and detailed recommendations for Phase B follow-on effort are recorded. A few of the more general recommendations are listed here in summary:

- Definition of the candidate HEAO-C experiments should continue. Minimization of HEAO spacecraft development costs for Missions A, B, and C requires timely identification of all principal requirements in order to reap full advantage from design commonality.

- The HEAO-C spacecraft concept developed during the Phase A effort is, for the most part, highly conservative. Although such a design approach is desirable during concept formulation and feasibility assessment, a more optimum, cost-effective design should result from Phase B definition. Phase B iteration of the Phase A design concept to more closely match the designs which evolve during the Phase C/D contracted effort for HEAO-A and -B should be directed toward this goal.

- Graphite/epoxy showed sufficient promise to be selected as the telescope tube material for the Phase A concept. However, continued in-depth assessment of this material is suggested during the Phase B effort.

- The requirement for the two year operational lifetime for HEAO-C with a two year reliability goal should be re-evaluated. Identical lifetime and reliability goals are recommended for all HEAO missions (A, B, and C) to minimize cost through system and component commonality.

- If HEAO-C is selected for an early Shuttle retrieval mission, then requirements for docking mechanisms and reentry Shuttle orbiter interfaces will be imposed on the spacecraft design. If this is the case, and launch schedules are not entirely incompatible, then designing for launch on either the Titan IIID/OAS or the Space Shuttle should be considered.

APPROVAL

NASA TM X-64652

HIGH ENERGY ASTRONOMY OBSERVATORY MISSION C PHASE A FINAL REPORT

Volume I — Executive Summary

By Program Development

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